The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden

(PERSGA)

Standard Survey Methods for Key Habitats and Key Species in the Red Sea and Gulf of Aden

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PERSGA is an intergovernmental organisation dedicated to the conservation of coastal and marine environments and the wise use of the natural resources in the region.

The Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment (Jeddah Convention) 1982 provides the legal foundation for PERSGA. The Secretariat of the Organization was formally established in Jeddah following the Cairo Declaration of September 1995. The PERSGA member states are Djibouti, Egypt, Jordan, Saudi Arabia, Somalia, Sudan, and Yemen.

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FOREWORD

PERSGA took the initiative during the execution of the Strategic Action Programme for the Red Sea and Gulf of Aden (SAP) to consider the importance of conserving regional habitats and biodiversity. The Habitats and Biodiversity Conservation (HBC) component of the SAP developed a strategy that contained five clear steps: (i) develop a set of standard survey methods (SSMs) for the region, (ii) train national specialists to use these methods, (iii) execute regional surveys, (iv) prepare conservation plans, and (v) implement the plans.

In order to evaluate and monitor the status of marine habitats and biodiversity within the Red Sea and Gulf of Aden, surveys must be undertaken that are comparable in extent, nature, detail and output. Standardising survey methodology within the region is essential to allow valid comparison of data, and for the formulation of conservation efforts that are regionally applicable.

The preparation of this guide to the Standard Survey Methods for Key Habitats and Key Species in the Red Sea and Gulf of Aden was initiated following a review of the methods currently in use around the world. Contextual SSMs were then drafted for each of the relevant fields: sub-tidal, coral reefs, seagrass beds, inter-tidal, mangroves, as well as for important groups such as reef fish, marine mammals, marine turtles and seabirds. The SSM guide was discussed at a regional workshop in September 2000 held in Sharm el-Sheikh where scientists from both inside and outside the region reviewed the first drafts and provided the authors with useful comments.

During 2001 PERSGA conducted a series of training courses for regional specialists to teach them some of these specific methods. The training courses were also used as tools to evaluate the methods and to determine their applicability to our region. The results of the evaluations given by the specialists recognized the suitability of these SSMs for our region due to a combination of factors: their widespread use, their simplicity and the particular adaptations made to suit the region.

We are proud to provide our region with this SSM guide. It has been recognized by experts from all over the world and tested by regional specialists. We hope this guide can be improved upon in the future and will play its part in achieving the goal of sustainable development of marine and coastal resourses in the region.

This guide will form an important tool to be used by management to help make decisions that will prevent an otherwise irreversible decline in the status of our marine habitats and species.

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ABBREVIATIONS AND ACRONYMS

ACCSTR	Archie Carr Centre for Sea Turtle Research
A-C-I	After-Control-Impact
AFDW	Ash-Free Dry Weight
AIMS	Australian Institute of Marine Science
ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
ARMDES	AIMS Reef Monitoring Data Entry System
ATV	All Terrain Vehicle
BACI	Before-After Control-Impact
CA	Correspondence Analysis
CARICOMP	Caribbean Coastal Marine Productivity
CCA	Canonical Correspondence Analysis
CCL	Curved Carapace Length
CCW	Curved Carapace Width
CI	Coral Replenishment Index
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CoT	Crown of Thorns (Starfish)
DAN	Diver Alert Network
DCA	Detrended Correspondence Analysis
df	Degrees of freedom
DIC	Dissolved Inorganic Carbon
EI	Exposure Index
EIA	Environmental Impact Assessment
EMR	Electro-Magnetic Radiation
FAO	Food and Agriculture Organization of the United Nations
GCRMN	Global Coral Reef Monitoring Network
GEF	Global Environment Facility
GIS	Geographical Information System
GPS	Global Positioning System
HW	Head Width
HWN	High Water Neap
HWS	High Water Spring
ICZM	Integrated Coastal Zone Management
IT	Information Technology
IUCN	World Conservation Union (formerly International Union for the Conservation of Nature and Natural Resources)
JICA	Japanese International Co-operation Agency
KSA	Kingdom of Saudi Arabia
LE	Lower eulittoral
LF	Littoral fringe
LWN	Low water neap
LWS	Low water spring
MBACI	Multiple Before-After Control-Impact
MDS	Multi-dimensional scaling

MEPA	Meteorology and Environmental Protection Administration (Saudi Arabia)
Mn	Median
MPA	Marine Protected Area
MS	Mean Squares
mtDNA	mitochondrial DNA
NCWCD	National Commission for Wildlife Conservation & Development (Saudi Arabia)
nDNA	nuclear DNA
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanographic and Aeronautical Administration
NPMANOVA	Non-Parametric Multivariate Analysis of Variance
ONC	Operational Navigation Charts
PC	Personal Computer
PCA	Principal Component Analysis
PERSGA	Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden
PL	Plastron Length
PQ	Permanent Quadrat
PTL	Permanent Transect Line
PVC	Polyvinyl Chloride
PW	Plastron Width
R/S	Root/Shoot ratio
RAM	Rapid Assessment Methods
RDA	Redundancy Analysis
REA	Rapid Ecological Site Assessment
RI	Rarity Index
RSA	Rapid Site Assessment
RSGA	Red Sea and Gulf of Aden
S	Species
SAP	Strategic Action Programme for the Red Sea and Gulf of Aden
SCA	Seabird Colony Register
SCL	Straight Carapace Length
SCUBA	Self Contained Underwater Breathing Apparatus
SCW	Straight Carapace Width
SD	Standard Deviation
SF	Sublittoral Fringe
SMP	Seabird Monitoring Programme
SS	Sum of Squares
SSM	Standard Survey Methodology
SST	Sea Surface Temperature
TL	Tail Length
TMRU	Tropical Marine Research Unit
TPC	Tactical Pilotage Charts
TWINSPAN	Two-way Indicator Species Analysis
UE	Upper Eulittoral
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNOPS	United Nations Office for Project Services

INTRODUCTION

The Red Sea and Gulf of Aden (RSGA) represent a complex and unique tropical marine ecosystem with an extraordinary biological diversity and a remarkably high degree of endemism. This narrow band of water is also an important shipping lane, linking the world's major oceans. The natural coastal resources have supported populations for thousands of years, and nourished the development of a maritime and trading culture linking Arabia and Africa with Europe and Asia. While large parts of the region are still in a pristine state, environmental threats notably from habitat destruction, over-exploitation and pollution are increasing rapidly requiring immediate action to conserve and protect the region's coastal and marine environment.

During the implementation of the Strategic Action Programme for the Red Sea and Gulf of Aden (SAP), PERSGA focussed attention on the conservation of regional habitats and biodiversity. A review of previous work in the region brought to light two important points. Some areas had received disproportionately more attention that others, and a variety of different survey methods had been used rendering a comparable analysis or synthesis of the data next to impossible. In order to evaluate the current status of key habitats and species within the region surveys had to be undertaken that were comparable in extent, nature, detail and output. To achieve this goal PERSGA initiated the preparation of a set of standard survey methods.

When used consistently over a period of time, the surveys will provide data that give an accurate and objective assessment of the true status of the region's biodiversity, acting as a cornerstone in the implementation of long-term monitoring programmes. Several chapters provide a range of alternative methods designed to suit surveys of increasing complexity when more detailed information is required. As the data collected using these methods will be comparable across the region, they will allow environmental changes to be detected and monitored at a regional level. Standardised data collection and analysis will also provide the necessary information from which similar, consistent, regional legal and executive frameworks can be developed for habitat and biodiversity conservation.

The key habitats and key species that are covered in this guide include: coral reefs, seagrass and seaweed beds, other subtidal communities, intertidal communities, mangroves and their associated fauna, as well as faunal groups such as reef fish, marine turtles, seabirds and marine mammals.

The standard survey methods (SSMs) were prepared by respected international experts with many years of experience in the region. Initially a review was made of methods currently in use in this region and elsewhere. Then the SSMs were drafted and tailored to suit the particular conditions of the region, taking into account the geographical variation within the Red Sea's northern, central, and southern sectors, and the Gulf of Aden. They were designed to be simple and straightforward, suitable for use in surveys, monitoring, and as a training guide. Though the methods are user-friendly, they are of sufficiently high accuracy to provide the minimum requirements needed to assess the status and health of environments and their constituent populations, and are able to account for bias introduced when surveys are conducted by different people, with different capacities and levels of training. The SSMs also allow for integration between surveys wherever possible (for instance the collection of turtle and dugong data during the same aerial survey).

A workshop was held in September 2000 in Sharm el-Sheikh to discuss progress with the SSMs. It provided an opportunity for participating experts from inside and outside the region to discuss the development of the methods. Following extensive discussions and refinement, teams of regional specialists were trained and the methods were field tested.

There are a number of general but important points that should be considered at the design stage before commencing any sampling programme. Variation is a characteristic of all biological systems. It is a natural phenomenon. If one of the objectives of the sampling programme is to detect the effect of human activities, then it will be essential to be able to differentiate between the natural or background variation, and any change supposedly caused by human interference in the ecosystem.

It is important therefore to know the biology of key species, to understand the ecology of the community under study. Knowledge of the feeding and reproductive behaviour, diurnal rhythms, migratory patterns, generation times, predator and prey relationships is essential to avoid making inaccurate deductions and hence devaluing the advice offered to environmental managers.

For example, a survey programme carried out over a number of years to assess populations of a small fish species in seagrasses beds, might suddenly show a collapse in numbers if the data collected in the first few years happened to be collected on a rising tide, whereas a later survey was conducted on a falling tide.

In northern or southern latitudes, reproductive cycles may be linked to seasonal changes. Closer to the tropics these environmental changes are less pronounced and generation periods may be different. Small, mobile species may have several generations within one year. Sampling at different times on an annual basis might strike natural peaks or troughs in population numbers leading to erroneous conclusions on the status of the population. Species with a naturally high temporal variability will need more frequent sampling.

It will be important to differentiate between natural disasters and anthropogenic influences. For example, a cold wet winter may be as or more devastating to a breeding seabird colony than a minor oil spill. It is important to understand the reproductive potential of a species, its ability to respond to normal events and to re-establish its ‘average’ population density in order to be able to give the appropriate weight to any recommendations for extra conservation measures.

Each chapter in this volume follows a broadly similar format: an introduction, a set of survey methods often of increasing complexity to allow researchers to collect data at different levels of precision, recommendations for statistical analysis and data presentation, a list of references and additional useful literature. The survey methods are complemented with line drawings where necessary and with survey sheets that can be readily photocopied for use in the field.

Data collected using the standard survey methods will be fully geo-referenced, collated at PERSGA headquarters and stored in a geographical information system (GIS) database. This will allow temporal and spatial changes to be displayed graphically and in a form suitable for a wide range of data users.

It is our hope that researchers in the region using these standard survey methods will suggest modifications and improvements that can be included in subsequent editions. All comments can be sent to PERSGA at the address given.

1

RAPID COASTAL ENVIRONMENTAL ASSESSMENT

1.1 INTRODUCTION

The Red Sea, together with the Gulf of Aden, constitutes the Red Sea Large Marine Ecosystem (SHERMAN 1994) or PERSGA region. Biological research in the region extends back to at least the 1700s, with an early emphasis on taxonomy (VINE 1985; SHEPPARD et al. 1992). Recent work has included ecological surveys of various intertidal biotopes (e.g. JONES et al. 1987; PRICE et al. 1987a; SHEPPARD et al. 1992; TURNER et al. 1999). Subtidal surveys have focused on coral reefs, although other hard substrata, seagrasses and sedimentary benthos have also been examined (reviews by SHEPPARD et al. 1992; MEDIO et al. 2000; SHEPPARD et al. 2000).

Assessments of environmental pressures and coastal management requirements have also been made (IUCN/MEPA 1987a,b). Of these, the recent Strategic Action Programme (SAP) for the Red Sea and Gulf of Aden has been particularly significant (PERSGA 1998). This sets out management interventions, at regional and national levels, for biodiversity conservation through marine protected areas and supporting measures. Following these and other initiatives (see PRICE et al. 1998), integrated environmental understanding of the PERSGA region has advanced considerably.

Site-specific data on resources, human uses and impacts represent a key input to coastal planning and management (PRICE 1990). However, this information is limited or absent for some PERSGA member states. Such information can be obtained more readily from broadscale, rapid environmental assessments than from focused disciplinary research. For these and other reasons, the value of rapid assessment is becoming increasingly recognised (reviews in PRICE et al. 1988; DEVANTIER et al. 1998). Comprehensive manuals describing methods and protocols have been developed (e.g. ENGLISH et al. 1997), ensuring comparability of approach so that regional comparisons are valid. However, the focus of these and most other rapid assessment approaches is generally on particular ecosystems, such as coral reefs, rather than on the coastal environment *per se* (i.e. mixed biotopes and ecosystems, species groups and environmental impacts).

This chapter outlines a rapid assessment technique developed for a comprehensive survey of the Red Sea and its natural systems during the 1980s, in conjunction with other methodologies. Unlike many other approaches, different resources (ecosystems and species) and associated impacts (uses and pressures) are examined concurrently, using the same scale for assessment, and within the same sample or observational unit. The same technique, with minor modifications, has subsequently been applied to several other regions of the world (see section 1.3.2). The merits and shortcomings of the technique are also described. The main emphasis of the chapter is on the methodology used for collecting and then analysing the data.

1.2 CHARACTERISTICS OF RAPID ENVIRONMENTAL ASSESSMENT

1.2.1 High-resolution data versus low-resolution data

Assessment of coastal systems in any region can be undertaken at a range of scales and intensities depending on several factors. These factors include:

- The main purpose of the investigation (the principal consideration),
- The type of coastal system being assessed,
- Physical, human and economic resources available, and related to this,
- The time available to undertake the assessment.

Some of the characteristics of rapid environmental assessment compared to more detailed, quantitative methodologies are summarised in Table 1.1. Detailed methodologies are used more commonly when the focus is on particular biotopes or ecosystems. These are described in other chapters. The 'detailed' and the 'rapid' methodologies represent two extremes. Clearly observations can be made and data collected using either approach, as well as a range of 'intermediate technologies'. A key concern for coastal management should not be whether detailed or rapid investigation is appropriate, but what balance or combination of methodologies best address the problems or issues. There is an inevitable compromise between low resolution data collected from many sites using low-cost methodologies, and higher resolution data from fewer sites using generally more costly methodologies.

It is also critical that social and political factors are fully taken into account. For example, while it might be considered necessary, technically, to undertake detailed assessment at the site of a proposed new hotel development, the developer may only be able or prepared to wait for a limited period before the survey results become available. Such urgency can be problematic unless rapid assessment is considered acceptable.

The overall benefits of rapid assessment methodologies compared with more quantitative surveys include: the provision of a thorough, integrated understanding of the coastal area, which is seldom possible through a more disciplinary focus; the feasibility of surveying extensive tracts of coastline (e.g. > 1,000 km) over relatively short time scales; the limited resources required (human, physical and economic). Set against these advantages, rapid assessment data is necessarily of lower resolution and hence more imprecise than more quantitative approaches.

1.2.2 Target and applications

Rapid assessment methods (RAMs) are an appropriate approach for the effective survey of relatively large areas of marine and coastal environment to help with the development and design of site-specific management plans for proposed marine protected areas (MPAs). Rapid assessment provides the first tier of survey methods for MPA surveys, with a subset of sites surveyed in more detail. RAMs are more widely applicable to general habitat, biodiversity, resource use and human impact surveys and assessments.

Further details of applications for which rapid assessment may be used are summarised in Table 1.2. This follows on from the information in section 1.2.1. Cross-reference is also made to the corresponding analytical techniques appropriate for generating this information. Applications here are divided into those associated with ecology, coastal planning or management and regional comparison, although these divisions may not always be clear.

Feature	Detailed assessment/sampling	Rapid assessment
Number of sites examined	Few	Many
Coverage/representativeness of coast	Low	High
Range of factors examined	Limited	Considerable
Detail of information for each factor	High	Low
Precision of data collected	High	Low
Technology/cost	Moderate/high	Low
Type of data generated	Parametric[1]	Non-parametric[2]
Statistical analysis possible	Parametric	Non-parametric
Types of statistical analysis possible	Univariate & multivariate	Univariate & multivariate

Table 1.1 Features of rapid assessment vs. detailed methodologies for coastal environmental assessment.

[1] 'Real' measurements, such as length of fish or actual number of birds, are examples of parametric data. For these measurements, provided they follow certain distributions (usually the normal), parametric statistics/tests can be performed. Examples include mean (average), Pearson's correlation coefficient (degree of association) and Student's *t* test (comparison).

[2] Ranked or ordinal data, for example the 0–6 scale used in the present rapid assessment, are an example of non-parametric data. For this type of data, corresponding non-parametric statistical tests must be used. For example median, Spearman's rank correlation, and Mann-Whitney *U* test, rather than mean, Pearson's correlation coefficient and Student's *t* test, which are the equivalent parametric tests. (Non-parametric tests should also be used when parametric data are not normally distributed).

Application or feature	Analytical/statistical technique (section 1.4.2)
A. ECOLOGY	
Community composition and biogeographic patterns/variability	a
Ground-truthing, e.g. of satellite imagery	b
B. COASTAL PLANNING, BIODIVERSITY CONSERVATION AND PROTECTED AREA MANAGEMENT	
Overall state of coastal environment: data summary for whole coast or particular region	c
Identification of resource-use conflicts	d
Selection of protected area sites using cluster analysis	e
Repeat surveys as part of monitoring programmes	f
C. REGIONAL COMPARISON AND GOVERNANCE	
Environmental comparison with other regions	g
Compliance with environmental legislation	h

Table 1.2 Uses and value of rapid assessment also showing corresponding analytical techniques (section 1.4.2).

1.3 METHODOLOGY

1.3.1 Survey design

The choice of locations (sites) for rapid assessment should be well integrated with the survey design planned for any parallel, detailed or quantitative surveys. To minimise bias, the coast may be divided up so that sites are more or less equidistant from each other. This will help to avoid any temptation to sample 'interesting' features (e.g. a large mangrove stand), perhaps at the expense of other less interesting areas, such as an open sandy beach.

An alternative view is that the coast should not be divided up equidistantly, but rather, should take into account features of the coast. For example, if 90% of the coast is sand beach and 10% mangrove, equidistant site selection might result in no mangrove being sampled, especially if it occurs as small stands. A random selection can still be achieved via a random stratified horizontal distribution of sites, where a similar number of sites are sampled within all features, thus ensuring that sites in mangrove are sampled as well as beach. Equidistant sampling will probably suffice on long homogeneous coasts where many sites are sampled (e.g. the Red Sea), but difficulties might be encountered on shorter heterogeneous ones (e.g. coast of Socotra).

For any region, the minimum number of sites examined should not be less than about 30 for statistical reasons and, if possible, substantially more. In the rapid assessment of the entire Red Sea coast of Saudi Arabia and islands (c. 2,000 km) conducted during the 1980s approximately 1,400 sites were surveyed (PRICE et al. 1998). The position of each site should be determined by Global Positioning System (GPS), recorded at a suitable point such as the mid point of a survey quadrat. This also facilitates revisiting sites during monitoring programmes.

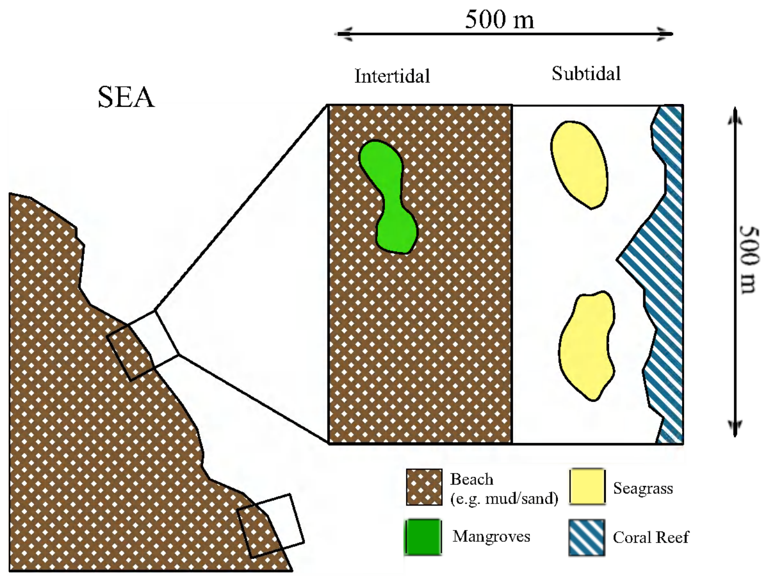

Figure 1.1 Schematic diagram showing configuration and dimensions of the 'site inspection quadrats' used in rapid environmental assessment. At each site, estimates are made of the abundance of key ecosystems and species groups, and also of human uses/environmental pressures (impacts) within 250,000 m^2 (i.e. 500 x 500 m).

ECOSYSTEMS/SPECIES		HUMAN USES / PRESSURES (IMPACTS)
Flora	**Fauna**	
Seagrasses	Reefs/corals	Oil
Algae	Birds	Human litter (plastics, metals, other solid waste)
Halophytes	Turtles[3]	Driftwood and wood litter
Mangroves	Mammals[4]	Construction/development
Freshwater vegetation	Fish	Fishing
	Invertebrates	

Table 1.3 Ecosystems, species groups, uses and impacts examined by rapid assessment. (Counts of empty nesting pits included in estimates of turtles, since information on nesting locations is important for management.)

[3]Useful to separate nesting females, turtle pits on the intertidal/landward component of the quadrat (both within 500 x 250 m) and swimming/feeding turtles in subtidal component of the quadrat (within 500 x 250 m).

[4]Useful to separate marine mammals (e.g. dugongs and dolphins) and terrestrial mammals (e.g. rats and mice, which can affect turtle and bird breeding). In areas such as Somalia and Sudan, terrestrial mammals of conservation significance (e.g. antelope) may be present and should be included in recordings. This provides a good example of how rapid environmental assessment can consider both marine and terrestrial conservation.

1.3.2 Overview of methodology

The use and application of a simple, well-proven yet robust technique for rapid environmental assessment is described below. The methodology was originally developed for the Red Sea (Dawson Shepherd & Ormond 1987; Jobbins 1996; Price et al. 1988, 1998). It has subsequently been utilised in other parts of the Arabian region (Price et al. 1987b; Price 1990; Price & Coles 1992; Price et al. 1993, 1994; Huntington & Wilson 1995; Wilson et al. 2003), as well as further afield in the Chagos archipelago, Indian Ocean, (Price 1999) and Cameroon, West Africa (Price et al. 2000).

Each coastal site comprises an 'inspection quadrat' about 500 x 500 m bisecting the beach, extending 250 m up the shore and 250 m down into the subtidal zone (Figure 1.1). The GPS position is recorded at the mid point of the survey quadrat. With experience, dimensions of the quadrat can be determined quite accurately, but initially use of GPS can facilitate this. However, it is worth emphasising that demarcation of the quadrat only needs to be an estimate, not an accurate measure. The intertidal/land component of the quadrat (500 x 250 m) is determined from observations while walking. The subtidal component (500 x 250 m) is examined while snorkelling. In some instances (e.g. Chagos), scuba-diving may be necessary in order to survey steeper drop-offs within 250 m from the shore. Within each quadrat, the abundance of biotopes (ecosystems) and species groups, and magnitude of uses and pressures (impacts) are estimated and recorded (Table 1.3). Further details are given below.

Observations at each site typically take about one hour. Clearly, a longer survey time than one hour for both intertidal and subtidal areas should be included if diving subtidal assessment is also required. During the planning of the survey it is important to allow sufficient time for transport between sites. Often this can be more time-consuming than the actual observations or rapid assessment.

Minor modifications to the methodology are needed if sites do not conform with the above configuration (i.e. 500 x 500 m). These are considered in section 1.3.3 in *Assessment of 'non-standard' coastal sites.*

1.3.3 Survey methods

Data sheets and recording

Data are recorded on special proforma data sheets, ideally of waterproof paper (Appendix 1.6.1). It may eventually be possible or desirable to record observations using a hand-held computer and GPS. Use of a mobile phone would allow transmission of survey data, already in spreadsheet or database format, back to 'home base'. This would help minimise errors during transcription of data from field notes, and also allow immediate computer analysis.

Ecosystems and species groups

A logarithmic scale of 0–6 (Table 1.4) is used for field estimates of the abundance of ecosystems and species groups. In the case of flora, corals, and reefs, scores are based on estimates of areal extent (m^2) within each sample area of 250,000 m^2 (500 x 500 m). In practice, this is often best determined by visual estimate of percentage cover from a number of spot assessments while snorkelling, then converting the results to the log abundance scale. For example, the results of estimation of seagrass cover during six representative spot dives might be: 50, 75, 60, 75, 20, and 90 per cent. The average value is about 60 per cent seagrass cover. This is equivalent to 0.6 x 500 x 250 (assuming

Ranked abundance/magnitude score (log scale)	Areal extent (m^2): flora and reefs or No. of individuals: other fauna (equivalent arithmetic range)
0	0
1	1-9
2	10-99
3	100-999
4[5]	1,000-9,999
5[6]	10,000-99,999
6	100,000 +

Table 1.4 Logarithmic ranked/ordinal scale of 0–6 used for abundance estimates of coastal ecosystems (flora and reefs) and species groups (fauna). The same scale is used to estimate the magnitude of uses/pressures (impacts).

seagrass is confined to the subtidal), i.e. 75,000 m^2. The corresponding log abundance value using the 0–6 scale would therefore be 5 (see Table 1.4).

For fauna, except corals and reefs, the same 0–6 scale is used, but here it reflects the estimated number of individuals (e.g. birds), again within each sample area of 250,000 m^2 (500 x 500 m). In some situations, the observer may consider it difficult to assign the correct abundance score in instances of very high faunal densities. For example, during a recent survey of the Chagos archipelago, seabirds were present in remarkably high numbers at some sites (thousands of individuals). Of significance, however, is that a log scale is used for rapid assessment. It therefore seems likely that visual estimation of birds, or other attributes, would be sufficiently accurate. For example, a bird population of only 1,000 is assigned the same abundance score as a population as high as 9,999 (i.e. 4; see Table 1.4). In the Chagos, validation of the technique was provided by the highly significant correlation observed between bird abundance values based on scores (0–6) derived from rapid assessment and actual counts made by a professional ornithologist (Peter Symens; PRICE 1999).

Though abundance values may be used for species groups of both flora and fauna, it is also possible to collect data for individual species. This was done for seagrasses (PRICE et al. 1988) as part of the rapid assessment of the Red Sea in the 1980s (PRICE et al. 1998). Clearly, the overall abundance value of a species group (e.g. seagrasses) cannot simply be obtained by adding abundance values for individual species, because of the log scale. For example, species abundance values for *Halodule uninervis*, *Halophila stipulacea* and *Halophila ovalis* might be 3, 2 and 3.

[5] Abundance value of '4' initially based on (semi-log) scale of 1,000–29,999, but later changed to fully log scale (1,000–9,999; see PRICE 1999).

[6] Abundance value of semi-log scale 30,000–99,999 initially adopted for abundance value of '5', but later changed to fully log scale (10,000–99,999; see PRICE 1999).

Summation of values would give 8 (The range of the scale is 0–6). Hence, the abundance value for each species must be first converted to abundance/cover in m^2, as indicated below.

Thus, the overall species abundance (all species) is 642 m^2, which on the (log) 0–6 scale is equivalent to 3 (Table 1.4).

As indicated earlier, rapid assessment of ecosystems and species groups may be augmented by more detailed quantitative surveys. Chapter 2 by Jones provides methods for sampling intertidal biotopes including mangroves and associated biota. In addition to detailed measurements, such as tree density, height, and girth at breast height, aerial photography is suggested as a means of determining the extent of mangrove cover. This supplements area estimates at sites determined by rapid assessment. Chapter 3 by DeVantier gives detailed sampling procedures for coral reefs, which includes percentage cover estimates at higher resolution than undertaken by rapid assessment. Similarly, chapter 5 by Kemp outlines survey approaches for hard and soft substrata and, again, percentage cover estimates are among the recommended procedures for hard substratum categories such as macroalgae. Sampling methods are also provided for unconsolidated sediments, devoid of marine flora. However, sediments and associated benthos are not among the attributes examined by rapid assessment.

Human uses and environmental pressures

A scale of 0–6 (Table 1.4) is also used to assess the relative magnitude (0: nil, 6: greatest impact) of fishing, construction or developments (e.g. ports and jetties) as well as oil, other impacts and driftwood, within the sample area of 250,000 m^2 (500 x 500 m). The latter is included since driftwood can discourage female turtles from crawling up beaches to nest and can, together with other solid waste, exacerbate problems of beach contamination in the event of an oil spillage.

Assessment of uses and pressures is undertaken as follows:

- Construction and development (e.g. jetties) and oil pollution according to (log) areal extent (0–6 scale), as used in estimates of floral and coral reef abundance (above) [7],
- Human litter (e.g. metal, plastics, other solid waste & pollution) and driftwood according to (log) number items (0–6 scale), as used in estimates of fauna, except corals (above) [7],
- Fishing: qualitative assessment of relative magnitude (0–6 scale) [8],
- Other impacts: crown-of-thorns (CoT) starfish and CoT scars – both according to (log) number (0–6 scale), as well as recent coral bleaching (white) and algal turf on coral/reef [9] – both according to (log) areal extent (0–6 scale); these are all coral/reef impacts.

Abundance value	Range	Geometric mean (of upper & lower value)
3	100-999	316
2	10-99	31
3	100-999	316
Total		**642**

In instances where attributes are not or cannot be quantified, a binary scale is utilised: 0 (absent) or + (present). The same scale is used for assessment of attributes outside the site inspection quadrat (right hand box or column on proforma data sheet; Appendix 1.6.1). For example, mangroves might be absent within the quadrat, but a large stand might occur one kilometre away, i.e. outside the quadrat. In such cases, it would be scored in the right hand box or column as '+', irrespective of its abundance.

Other recorded data

Physical features recorded on the proforma data sheets include details of the shore profile, substratum type and surface salinity; the latter measured with a hand-held refractometer. In addition, qualitative notes on the environment can be made. Photographs are also valuable, and details of the film and frame number should be included. Photographic records were particularly valuable during rapid assessment of the Gulf coast of Saudi Arabia both before (PRICE 1990) and after the 1991 Gulf War (PRICE et al. 1993, 1994). This provided a useful, visual record of changes in oil pollution along the shore.

Assessment of 'non-standard' coastal sites

In some instances, coastal sites may be encountered in the PERSGA region that do not fit the standard quadrat configuration of 500 x 500 m (i.e. intertidal or land component 500 x 250 m and subtidal component 500 x 250 m). These situations are likely to include:

1. sites having only a subtidal component (e.g. a patch reef);
2. sites having an intertidal/land component which is smaller than the standard size configuration of 500 x 250 m, such as a small island, but having the normal subtidal component (500 x 250 m);
3. sites having a steep cliff on shore or a steep drop off offshore but within the 250 m sections of intertidal and subtidal zone (e.g. Socotra). These clearly have little area value horizontally, but both provide substantial habitat area vertically.

Notes to facilitate assessment of these 'non-standard' coastal sites are provided in Appendix 1.6.2. In both situations, it might be appropriate to identify or highlight such sites in the computer database (e.g. *, ** and *** for situations one, two and three respectively).

1.3.4 Data storage

Data recorded on the pro-forma recording sheets (Appendix 1.6.1) should be transferred to a computer database, preferably MICROSOFT

[7] A modification of the qualitative assessment of relative magnitude of each impact to a semi-quantitative assessment is given in PRICE (1999).

[8] Fishing is perhaps the most difficult attribute to assess. A semi-quantitative index can be obtained by summing the lengths of boats and nets recorded at a site to give a yardstick of fishing effort, and simply ranking the data uniformly into in a 0–6 scale (where 0 indicates no boats or nets, and 6 indicates the maximum value of lengths of boats + nets recorded during the survey (PRICE et al. 1998). However, inter-regional comparison may be problematic using this approach, and a simple qualitative assessment of the magnitude of fishing (0–6 scale), as originally devised, may prove to be more satisfactory. In addition to direct fishing, it may be useful to assess indirect fishing, semi-quantitatively, for example as the number (converted to 0–6 scale) of discarded nets and discarded pots ('ghost' gear). Besides accounting for 'size' of fishing unit as described, some assessment is required of the number of vessels actually in use, rather than simply available, i.e. drawn up on shore. Many boats spend much of their life on shore, and hence this affects real estimates of fishing effort.

[9] Algal turf on reefs can be associated with a number of conditions, including colonisation of reef corals during a post-bleaching period.

	Mainland sites		Mainland and offshore (island) sites combined	
Attribute	R_S	p	R_S	p
ECOSYSTEMS & SPECIES				
Mangrove	- 0.44	< 0.001	- 0.26	< 0.001
Seagrasses	- 0.14	< 0.001	- 0.01	NS
Halophytes	- 0.03	NS	0.08	NS
Algae	- 0.53	< 0.001	- 0.46	< 0.001
Freshwater vegetation	0.01	NS	0.03	NS
Reef	0.41	< 0.001	0.29	< 0.001
Birds	- 0.58	< 0.001	- 0.48	< 0.001
Bird nesting	- 0.07	NS	- 0.13	< 0.001
Turtles	- 0.13	< 0.001	- 0.14	< 0.001
Turtle nesting	0.12	< 0.001	0.07	NS
Terrestrial mammals	- 0.27	< 0.001	- 0.2	< 0.001
Marine mammals	- 0.12	< 0.001	- 0.19	0.001
Fish	- 0.28	< 0.001	0.4	< 0.001
Invertebrates	- 0.74	< 0.001	- 0.74	< 0.001
USES/IMPACTS				
Construction	0.02		0.04	NS
Fishing	- 0.07	NS	- 0.07	NS
Beach oil	0.28	< 0.001	0.24	< 0.001
Human litter	- 0.08	NS	- 0.05	NS
Wood litter	- 0.13	< 0.01	- 0.1	< 0.01

Table 1.5 Correlations between latitude and abundance/magnitude of ecosystems, species groups, uses and impacts in the Saudi Arabian Red Sea using the Spearman's rank correlation coefficient (R_S)[10]; p = degree of significance; NS = not significant (from PRICE et al. 1998).

EXCEL or ACCESS. This facilitates data storage, access, manipulation and analysis. As on the data sheet, rows represent different sites, and columns different attributes (ecosystems, species groups, impacts).

1.4 DATA ANALYSIS

1.4.1 Statistical software

Many types of analysis can be performed using rapid assessment data. Analyses are shown below in relation to particular topics, problems and issues (see also Table 1.2). Software that may be useful include: MICROSOFT EXCEL or STATVIEW (univariate statistics) and STATISTICS (multivariate statistics: cluster analysis and/or multidimensional scaling); see SHEPPARD (1994). However, in the absence of analytical software, simple and useful data manipulation and analysis may still be performed manually. This might be a significant issue for some regional states where information technology constraints prevail.

[10] Since the data are non-parametric, Spearman's rank correlation coefficient (R_S), rather than Pearson's correlation coefficient (parametric test) must be used to determine strength of correlation. As with other tests, significance is determined using conventional statistical tables.

1.4.2 Analyses in relation to particular issues or problems

a) Community composition and biogeographic patterns/variability

Latitudinal or other trends in abundance of ecosystems or species groups or magnitude of use or pressures can be determined readily from rapid assessment data sets. This is illustrated by analysis of Red Sea data (PRICE et al. 1998). The abundance of most ecosystems and species groups increased significantly towards the southern Red Sea, with only reefs and turtle nesting (coastal sites only) showing greater abundance to the north (Table 1.5). Fish were significantly more abundant towards the south at coastal sites, but the reverse pattern was evident for the offshore sites. Of the human uses and impacts recorded, the magnitude of beach oil was greater in the north, whereas wood litter showed the opposite trend (Table 1.5). Latitudinal correlations with other uses and impacts were not significant.

Similar analyses can be done for individual species, such as seagrass. Using the same dataset for the Red Sea (PRICE et al. 1988, 1998), overall seagrass abundance and abundance of at least five taxa increased significantly towards the south: *Halophila ovalis*, *Halodule uninervis*, *Thalassia hemprichii*, *Cymodocea* spp. and *Enhalus acoroides*. The reverse pattern was shown by three species: *Halophila stipulacea*, *Syringodium isoetifolium* and *Thalassodendron ciliatum*.

b) Ground-truthing, e.g. of satellite imagery

Use of satellite imagery or other remotely sensed data requires ground-truthing to verify the occurrence of a particular intertidal or subtidal feature on the image (e.g. mangrove, coral, causeway). An extra tier of detail in the form of semi-quantitative information can be usefully provided, with minimal time and effort, by the collection of rapid assessment data.

This will need to take into account the 500 x 500 m survey area in relation to the resolution, and hence pixel size, of a satellite image. When ground-truthing satellite imagery, survey sites should endeavour to cover a homogeneous area represented by a central pixel identifiable in a habitat class in the image, surrounded on all sides by similar pixels, i.e. a minimum area of 3 x 3 pixels. Thus, when using LANDSAT imagery, where the resolution is 30 m (and hence pixel size is 30 m x 30 m), the minimum area to survey for one ground-truth observation is 90 x 90 m which is well covered by the 500 x 250 m of the Rapid Site Assessment method explained here. When using SPOT the pixel size is 20 x 20 m. Thus an intertidal or subtidal part of the survey area covers around 8.3 x 16.6 pixels in LANDSAT, and 12.5 x 25 pixels in SPOT. Given that these areas are relatively large, they may represent heterogeneous rather than homogeneous parts of the satellite image, i.e. cover several different classes of pixels, representing more than one habitat type. Thus sub-sampling, to capture the second tier of data (above) would be required for ground-truth work. This is more likely around smaller features, such as islands, rather than extensive beach systems.

c) Overall state of coastal environment: data summary for whole coast or region

The status of the coastal and marine environment can be determined simply from a table showing the following for each ecosystem, species group and use or pressure (impact):

- Range of abundance or magnitude values (upper and lower value)
- Prevalence (%)
- Median (Mn).

	CHAGOS (1996: 21 sites)			ARABIAN GULF (1986: 53 sites)			RED SEA (1982-84: 1 400 sites)			CAMEROON (1996: 36 sites)		
Attribute	Range [a]	Preval-ence (%)[b]	Median (Mn) [c]	Range	Preval-ence (%)	Median (Mn)	Range	Preval-ence (%)	Median (Mn)	Range	Preval-ence (%)	Median (Mn)
ECOSYSTEMS AND SPECIES												
Mangroves	(0)	(0)	(0)	0-6	6	0	0-6	29	0	0-6	8	0
Seagrasses	(0)	(0)	(0)	0-6	46	0	0-6	52	3	0-2	< 1	0
Halophytes	(0)	(0)	(0)	0-6	74	4	0-6	73	3	0-1	< 1	0
Algae	2-6	100	4	0-6	90	4	0-6	75	3	0-5	58	1.5
Freshwater vegetation	4-6	100	6	0-3	4	0	0-6	11	0	0-6	94	6
Reefs	1-5	100	5	0-3	19	0	0-6	53	2	0-3	8	0
Birds	1-4	100	2	0-3	75	1	0-5	49	0	0-2	58	0
							0-5[1]	11[1]				
Turtles	0-1[1]	19[1]	0	(0)	(0)	(0)	0-2	7	0	(0)	(0)	(0)
							0-3[1]	8[1]				
Mammals	0-1[2]	38[2]	0	(0)	(0)	(0)	0-2	3	0	0-2	8	0
							0-4[2]	14[2]				
Fish	4-6	100	5	0-4	36	0	0-6	84	1	0-4	11	0[3]
Invertebrates	4-6	100	6	0-6	98	6	0-6	85	5			5

Table 1.6 Summary of environmental data for Chagos (Price 1999) and comparison with 'sites' assessed using the same methodology: Arabian Gulf pre 1991 Gulf War data (Price 1990), Red Sea (Price et al. 1998) and Cameroon (Price et al. 2000). Data shown are abundance of ecosystems and magnitude of human uses/impacts using ordinal data (0–6 scale) collected during rapid coastal assessments.

USES/IMPACTS												
Construction	0-5	10	0	0-5	28	0	0-6	23	0	0-6	75	3
Fishing	(0)[4]	(0)[4]	(0)	0-3	26	0	0-6	39	0	0-2	47	0
Beach oil	0-1	38	0	0-6	77	2	0-5	45	0	0-2	36	0
Human litter	1-4	100	4	0-5	87	3	0-5	68	1	0-6	97	3
Wood litter	1-3	100	1	2	0-5	2	0-5	62.7	1	0-5	83	2

Notes for table:

a The minimum and maximum score using (0–6 scale) recorded during the survey.

b The percentage of sites having a particular attribute, such as mangroves, irrespective of its abundance score (i.e. > 0).

c The average value. Because the data are non-parametric, medians rather than means should be used, even though the latter have been used during some previous assessments (e.g. PRICE 1990).

1 Nesting individuals or tracks (turtles) only.

2 Rats were the only mammals recorded in the study, but quantitative estimates could not easily be made. In order that the data could be used in the cluster analysis, abundance values of 1 were given (somewhat arbitrarily) for mammals.

3 Fish observations influenced by very poor visibility at virtually all sites.

4 Part of a fish trawl was observed on Petit Mapou, an island near to Ile Diamont, Perros Banhos. A fishing float or marker was also observed on Petite Coquillage, Peros Banhos. However, these observations are not necessarily an indication of fishing on these islands.

Site reference (see JOBBINS 1996)	Latitude (°N)	Reefs/Corals	Construction	Beach oil
		Abundance/magnitude value *(NR: no record)*		
12d15	18° 12.6'	4	5	0
01g02	28° 28.8'	4	6	NR
01g08	28° 27.0'	4	6	NR
03a05	27° 22.2'	4	5	NR
03a06	27° 20.4'	4	5	1
04a07	26° 13.8'	4	5	1
04a08	26° 14.4'	4	6	NR
04b01	26° 13.8'	4	5	NR
04b05	26° 09.0'	4	1	5
05e17	24° 42.6'	4	0	5
06a04	24° 16.2'	4	5	NR
06e06	24° 04.8'	4	6	NR
06h02	23° 57.0'	4	5	+
07i03	22° 34.2'	4	6	NR
08c10	22° 07.2'	4	5	NR
08c12	22° 06.0'	4	5	NR
08d08	21° 48.0'	4	5	NR
08d14	21° 43.2'	4	5	NR
08e02	21° 43.2'	4	5	NR
08e07	21° 40.8'	4	5	1
08e08	21° 40.2'	4	5	NR
08e09	21° 39.0'	4	5	NR
08e10	21° 38.4'	4	5	0
08e11	21° 36.0'	4	5	NR

Table 1.7 Illustration of use of the database for identifying sites associated with actual or potential resource-use conflicts in the Saudi Arabian Red Sea. Using a 0–6 scale, the example lists all coral reef sites associated with high coral abundance (> 3), intensive levels of construction (> 4) and/or high levels of beach oil (> 4). All of the 24 sites listed are in the central or northern Red Sea (~ latitude 18–26°N), and mostly in the vicinity of Jeddah (~ latitude 21°N) (from PRICE et al. 1998).

An example is shown using data from the Red Sea and several other regions (Table 1.6). More detail, if required, can be given in the form of frequency of abundance/magnitude scores (PRICE et al. 1998, – Appendix 1.6.2).

d) Identification of resource-use conflicts

A database containing rapid assessment data can be easily interrogated to define the principal environmental features of a site or region. Of particular significance are the locations of areas where biological resources do and do not overlap with resource-uses and impacts. Overlapping areas denote locations of actual or potential conflicts, where management may be urgently needed. Non-overlapping areas signify resource-use compatibilities, and hence locations where there may be openings for further resource use and coastal development.

A simple illustration of this application is given in Table 1.7 using rapid assessment data for the Red Sea coast of Saudi Arabia. The table lists all sites associated with high coral abundance (> 3), intensive levels of construction (> 4) and/or high levels of beach oil (> 4). All of the 24 sites listed are in the central or northern Red Sea (~ lat. 18–26°N), and mostly in the vicinity of Jeddah (~ lat. 21°N). The listing of sites may be underestimated due to the high occurrence of zero records for beach oil. More complex assessments can be made and specifications set (i.e. resource abundance and use/impact magnitude) at the level of sensitivity required by the manager. More generally, the database can be used to generate a snapshot of environmental conditions in a particular area, for example as a precursor to a more comprehensive environmental assessment.

e) Selection of protected area sites using cluster analysis

Multivariate procedures can be used to determine structure and patterns in biological or other environmental data. These commonly include cluster analysis and/or multidimensional scaling (MDS). Although not statistical tests, these are valuable interpretative tools. Cluster analysis [11] is used here to compare, separate and classify sites into groupings according to the environmental attributes recorded at each site by rapid assessment. The resulting dendrogram graphically depicts groupings of the different sites and their affinities with each other.

Rapid assessment data from the Red Sea coast of Saudi Arabia are used here to illustrate the application of cluster analysis. Ecosystem and species abundance data from the coastal and offshore sites are pooled using median values for each degree of latitude (Table 1.8). This reduces the number of ‘sites’ to a manageable number. At a similarity level of 0.43, three groups (I–III) are identified by latitudinal band (Figure 1.2). Group I is composed of all northern sites (26–29°N) plus latitude 21°N sites; Group II sites fall within central latitudes (20°N, 22–25°N), and Group III comprises southern Red Sea sites (16–19°N). The environmental diagnostics of each group are shown in Table 1.9. Group I sites appear to be the most impacted, and Group II sites the least. It is noted that Jeddah, a heavily developed coastal area, is situated at *c*. 21°N which may partly explain the absence of latitude 21°N sites from Group II and inclusion in Group I (Figure 1.2).

These findings have major implications for coastal management. For example, representativeness of habitats and species is recognized as an important criterion in the selection of marine protected areas (Gubbay 1995). Hence, in the example given, it might be appropriate to select candidate sites for marine protected areas from the (three) different groupings, to ensure that a range of biological or environmental characteristics are adequately safeguarded (see also Price 1990).

[11] Cluster analysis may be viewed as having four main stages (Sheppard 1994): (1) the data file or table is compiled with sites as rows and data columns as attributes; missing data for any attribute results in exclusion of the entire site from the cluster analysis; (2) a matrix of similarities or correlations is calculated, in which each site is compared with every other site. Several different indices can be used, including the Bray Curtis index, the most commonly adopted quantitative index; (3) clustering is carried out on the matrix. Here, the two sites which are the most similar are 'fused' to make a cluster. The cluster is then regarded as being one 'site', and its similarity with every other site is then recomputed, based on some measure of similarity of its components to the other sites. Four clustering procedures are offered in the software of Sheppard (1994). In the group average method, sites A and B have been fused to form cluster AB. Its similarity coefficient with C is computed as the coefficient of A with C plus coefficient of B with C, divided by two; i.e. it is the average of the two. It is straightforward and probably best understood by users (Sheppard 1994); (4) a dendrogram (e.g. Figure 1.2) is plotted, which is a graphical representation of step three (above).

	Mn values by latitude (°N)													
Attribute	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
Mangrove	2.5	0	0	1	0	0	0	0	0	0	0	0	0	0
Seagrasses	4	0	0	0	2	0	3	3	2	3	2	1	1	2
Halophytes	0	0	0	3	3	1	3	3	2	3	2	1	1	3
Algae	5	4	4	2.5	0	4	3	3	0	0	0	0	0	2
Freshwater vegetation[12]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reefs	0	0	3	3	0	4	2	0	3	3	4	4	4	4
Birds	2	2	2	1	1	0	0	0	0	0	0	1	0	0
Bird nesting[12]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turtles[12]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Terrestrial mammals[12]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marine mammals[12]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish	3	2	1	1	1	0	0	0	0	0	2	2	1.5	-
Invertebrates	6	6	6	5	2.5	1	2.5	1	0	3	0	0	0	2

Table 1.8 Median (Mn) values of biological data for all sites along the Red Sea coast of Saudi Arabia grouped by latitude for use in cluster analysis (from PRICE et al. 1998).

	Median (Mn) values for sites		
ECOSYSTEMS & SPECIES *(factors used in cluster analysis)*	Group I	Group II	Group III
Seagrasses	0	2	0
Halophytes	2	3	1
Algae	0	0	4
Reefs	4	2	0
Fish	0	0	2
Invertebrates	0.5	1	6
USES/IMPACTS *(factors not used in cluster analysis)*			
Beach oil	1	0	0
	2	0	1
Wood litter	1	0	1

Table 1.9 Environmental diagnostics of the three groupings derived from cluster analysis of biological data, using data from the Saudi Arabian Red Sea as an example. Median values for mangroves, freshwater vegetation, birds, bird nesting, turtles, turtle nesting, terrestrial mammals, marine mammals, construction and fishing were zero, and are not shown in the table (from PRICE et al. 1998).

[12] Attributes shown here, but data not used in cluster analysis due to occurrence of median values of zero for all latitudes.

	Coastal ecosystems						Pollution/impacts		
	Halophytes	**Algae**	**Seagrasses**	**Birds**	**Invertebrates**	**Fish**	**Oil (metal plastics etc)**	**Other**	**Wood**
1986									
All sites	2.47	3.33	1.77	1.06	5.31	0.63	1.77	2.29	2.11
N sites	3.23	3.69	2.06	0.65	5.53	0.33	2.24	2.65	2.65
S sites	1.71	3.00	1.47	1.44	5.11	0.93	1.33	1.94	1.61
N vs. S sites	$p < 0.05$	NS	NS	$p < 0.01$	NS	NS	NS	NS	NS
1991									
All sites	2.54	4.97	2.06	1.46	5.45	3.63	3.20	2.68	2.15
N sites	2.65	5.29	1.82	1.12	5.12	3.65	5.00	2.69	2.50
S sites	2.44	4.67	2.28	1.78	5.78	3.61	1.50	2.67	1.83
N vs. S sites	NS	NS	NS	$p < 0.05$	NS	NS	$p < 0.01$	NS	NS
Heavily oiled sites (6)	3.33	5.58	1.75	0.75	5.17	3.08			
Other sites (< 6)	2.13	4.65	2.22	1.83	5.61	3.91			
Heavily oiled sites (6) vs. other sites (< 6)	NS	NS	NS	$p < 0.01$	NS	NS			
1986 vs. 1991									
All sites	NS	$p < 0.01$	NS	$p < 0.05$	NS	$p < 0.01$	$p < 0.01$	NS	NS
N sites	NS	$p < 0.01$	NS	NS	NS	$p < 0.01$	$p < 0.01$	NS	NS
S sites	NS	$p < 0.01$	NS	NS	NS	$p < 0.01$	NS	NS	NS

Table 1.10 Summary statistics for abundance and use/impact data collected along the Saudi Arabian Gulf coast during 1986 and 1991. Values shown are average abundances (ecosystems/species) or magnitudes (uses/impacts). Significance of difference based on Mann-Whitney *U* test[13]; NS not significant at 95% level (from PRICE et al. 1993).

[13] Mann-Whitney *U* test is used because the rapid assessment data are non-parametric. For data which are parametric (and normally distributed) a Student's *t* test is used.

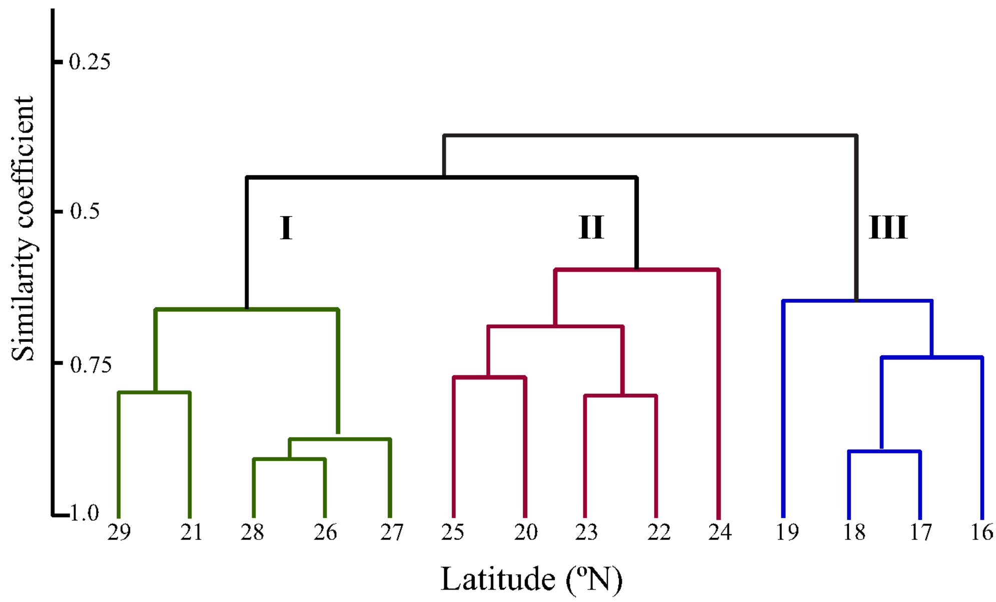

Figure 1.2 Cluster analysis of biological resource data for coastal and offshore sites along the Red Sea coast of Saudi Arabia. At a similarity level of 0.43 three groupings (I–III) occur (from PRICE et al. 1998). Data from sites are pooled using median values for each degree of latitude (see Table 1.8). Data for individual sites are given in JOBBINS (1996).

f) Repeat surveys as part of monitoring programmes

Rapid assessment has proved to be a useful monitoring tool. In the Gulf, comparisons in abundance and magnitude of ecosystems and uses or pressures were made between a pre-war period (1986) and post-war periods (1991, 1992, 1993, 1994). Summary data are shown in Table 1.10. Statistically significant changes are indicated below, further details being given in PRICE et al. (1993):

- Oil pollution significantly greater in 1991 (average 3.2) than 1986 (average 1.8).
- Oiling significantly greater at sites to north than south of Abu Ali in 1991, but not in 1986.
- Algae, bird and fish abundances significantly greater in 1991 than 1986.

g) Environmental comparison with other regions

Regions assessed using the same rapid assessment methodology can be easily compared. As an example, Table 1.6 (above) compares four different regions, including the Red Sea, in terms of abundance of ecosystems, species groups and magnitude of use/impacts. From these data sets, it is evident that beach oil is most prevalent and severe in the Arabian Gulf, whereas human litter (plastic, metal, other junk and debris) was most prevalent and severe in Chagos. Wood litter (driftwood) was recorded in all four regions but generally in relatively low quantities.

Several differences and similarities in terms of ecosystems and species groups are also evident at a broad level. Mangroves, halophytes and seagrasses were not recorded in Chagos, in contrast to the Red Sea and Gulf, where halophytes and seagrasses in particular were prevalent and/or abundant.

Halophytes were also not recorded in Cameroon, and seagrasses were virtually absent. Freshwater vegetation was prevalent and abundant in both Chagos and Cameroon, but not in the Arabian Gulf or Red Sea where the environment is far more arid. Reef or coral abundance was far greater in Chagos than in the other regions, particularly Cameroon, where only non-reef-building (ahermatypic) corals were observed. Further details are given in PRICE (1999).

h) Compliance with environmental legislation

From semi-quantitative or even qualitative inspection of national and regional data sets derived from rapid assessment, an indication of the extent of compliance with national, regional or international environmental legislation will become evident. Hence the localities (or regions) where management action is necessary can be identified. For example, the relatively heavy oil pollution along the shores of the Arabian Gulf coast of Saudi Arabia, even before the 1991 Gulf War (Table 1.6), might suggest that laws applying to oil pollution need to be upheld more firmly.

1.4.3 The role of rapid assessment data in the coastal planning and management cycle

Coastal management is a process involving a number of steps, which are shown schematically in Table 1.11 and Figure 1.3. This process is cyclical rather than linear. Particularly important is the feedback from monitoring (and consultation and participation), which should result in regular review of the management plans.

Such frameworks provide a mechanism for implementing the measures of international, regional and national programmes. Clearly, rapid assessment data provide a key input to step two (data

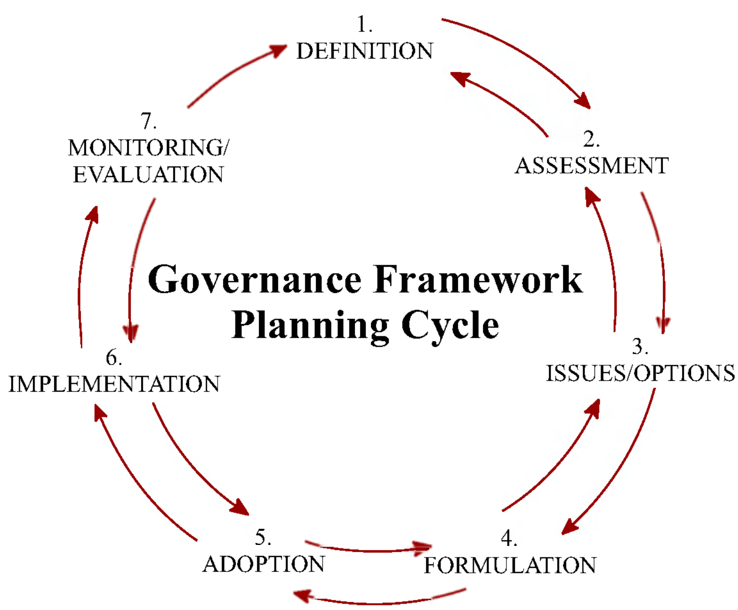

Figure 1.3 Graphic representation of key steps in coastal management, planning and decision making (from PERNETTA & ELDER 1994; see also Table 1.11).

collection and compilation) and step three (data analysis) to determine issues and options. This facilitates integrated coastal area management, by determining options and priorities for the use and management of coastal and marine resources. It provides guidelines and proposes what actions are needed to place human uses of a region onto a more ecologically and economically sustainable basis. This helps to balance the needs of conservation and development.

1. Problem Definition (Objectives) Here the objectives and scope of the problem or strategy are identified. Clearly, the objectives defined and agreed determine all future steps of the decision-making process including subsequent actions.
2. Assessment (Data Collection and Compilation) This entails collection of data on aspects of biodiversity, the environment and also human, legal, socio-political and related issues. This can be acquired using available information, and/or data from field surveys, interviews and other sources. Geographical Information Systems (GIS) allows periodic updating of information. This phase does not involve data analysis or interpretation (see below), without which data and databases are of only limited value.
3. Issues and Options (Data Analysis) This concerns data analysis to define and quantify actual or potential problems, opportunities and other issues; in this context relating to biodiversity conservation. Issues, problems and opportunities can be identified in different ways such as: i) map analysis, including use of GIS, for instance to identify areas of resource-use conflict and compatibility; ii) statistics, modelling and other numerical analyses, for example fishery stock assessment, or determining the effects of sewage on coral reefs and reef fisheries; iii) issue analysis, to help understand problems such as common resource property rights, or assessment of institutional capabilities; iv) integrated analysis (i-iii), for example to determine expected costs, impacts, benefits and options concerning a proposed tourist resort. Innovative software systems are currently under development to undertake complex analyses such as these and to facilitate coastal management in other ways.
4. Formulation (Data Synthesis) This involves data synthesis, using the results of the preceding two phases, to formulate an action plan, strategy or any other decision. These usually consist of a series of operational tasks (e.g. provisions of protocols). Tasks may be divided into those relating to the entire coast, country or region (i.e. broadscale) and those targeted at particular coastal areas (e.g. protected areas, habitat restoration).
5. Adoption Legislation is normally required for adoption of a plan, or decision, although in certain situations voluntary action can occur.
6. Implementation Once a strategy, plan or action has been adopted, or agreed upon, it needs to be implemented. Here practical considerations are important (e.g. human and physical resources), and collaborative support may be needed. This phase often includes the development and implementation of management plans (e.g. for coastal and marine protected areas).
7. Monitoring / Evaluation / Enforcement This includes assessing the effectiveness of the action plan, and components of it. As with Environmental Impact Assessment (EIA), comparison can be made between expected and actual results and adjustments to the plans made as necessary.

Table 1.11 Key steps in coastal management, planning and decision making (see also Figure 1.3).

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Appendix 1.6.1 Proforma datasheet for rapid assessment (ideally waterproof paper used).

Latitude	**Longitude**	**Source**	**Nearest name on map/chart**	**Sector Code**
Researcher	**Details of location**			**Date Code**

PROFILE				
FLORA	**1 Mangroves**			
	2 Seagrass			
	3 Halophytes			
	4 Algae			
	5 Freshwater Vegetation			
	6 Other			
FAUNA	**7 Reefs & corals**			
	8 Birds			
	9 Turtles Nesting females Pits Swimming turtles			
	10 Mammals Terrestrial Marine			
	11 Fish			
	12 Invertebrates			
	13 Other			
IMPACTS	**14 Construction**			
	15 Fishing/ Collecting Direct Discarded nets Discarded pots			
	16 Pollution Oil Metal/litter/junk Driftwood			
	17 Other Cr-of-thorns (CoT) CoT (scars) Recent coral bleaching (white) Algal lawn on coral			
OTHER	**18 Oceanography**			
	19 Meteorology			
	20 Other			

Photographic Record	

Appendix 1.6.2 Notes on the assessment of 'non-standard' coastal sites.

(1) Assessment of sites having only a subtidal component

A note should be made on the proforma data sheets of all such sites, i.e. one in which the intertidal/land component is absent.

Here the site inspection quadrat is now effectively only 500 x 250 m (rather than the standard 500 x 500 m). The various biological and physical attributes are assessed as follows:

- mangroves (absent – since no intertidal);
- seagrass (observation area 500 x 250 m – as for standard quadrat);
- halophytes (absent – since no intertidal);
- freshwater vegetation (absent – since no intertidal);
- reefs and corals (500 x 250 m – as for standard quadrat);
- birds (observation area 500 x 250 m – with note that intertidal component of quadrat, i.e. 500 x 250 m, absent);
- turtles (observation area 500 x 250 m – with note that intertidal/land component of quadrat, i.e. 500 x 250 m, absent);
- mammals (observation area 500 x 250 m – with note that intertidal/land component of quadrat, i.e. 500 x 250 m, absent);
- invertebrates (observation area 500 x 250 m – with note that intertidal component of quadrat, i.e. 500 x 250 m, absent);
- construction (observation area 500 x 250 m – with note that intertidal/land component of quadrat, i.e. 500 x 250 m, absent);
- fishing/collecting (observation area 500 x 250 m – with note that intertidal component of quadrat, i.e. 500 x 250 m, absent);
- pollution: all forms (observation area 500 x 250 m – with note that intertidal component of quadrat, i.e. 500 x 250 m, absent);
- other impacts, as specified in Appendix 1.6.1, are all coral/reef related (observation area 500 x 250 m – as for standard site inspection quadrat).

(2) Sites having intertidal/land component smaller than standard size

A note should be made on the pro-forma data sheets of all sites in which the intertidal/land component is smaller than the standard dimension of 500 x 250 m. The actual area (m^2) of this component should also be recorded, subsequently if necessary (e.g. from a map or satellite imagery).

The abundance of ecosystems/species and magnitude of uses/pressures (impacts) should be maintained as absolute (not modified to relative) values. The scales used are therefore the same as if the site had the dimension of a standard site inspection quadrat (500 x 500 m).

Hence, if the intertidal/land component of the quadrat is only 1,500 m^2, and this whole area is occupied by mangroves (100% cover), the mangrove abundance score given would be 4 (1,000–9,999; Table 1.4).

(3) Sites having a steep cliff on shore or a steep drop off offshore but within the 250 m sections of intertidal and subtidal zone (e.g. Socotra)

These clearly have little area value horizontally, but both provide substantial habitat area vertically. It might be appropriate/possible to assess using the same approaches used for the more 'normal' horizontal habitats, also making a note in the database of such instances (see section on assessment of non-standard coastal sites).

2

INTERTIDAL AND MANGROVE

2.1 INTRODUCTION

Shores of the Red Sea and Gulf of Aden are backed by an arid zone and in general are fronted by fringing or patch coral reefs. Rocky shores are usually of raised Quaternary fossil coral and either form steep undercut cliffs or reef flats cut by wave action. Inlets (sharms or wadis) occur at intervals formed by drowned river valleys and provide areas of sheltered soft sediment forming sand beaches, mudflats with associated salt marsh and mangrove. Shore temperatures range from a winter minimum of 8°C in the northern Red Sea, often with a diurnal change of 20°C, to 14°C in the central Red Sea, but are fully tropical in the southern Red Sea and Gulf of Aden. Salinities range from 39–41 ppt at sea, but may rise to hyperhaline (80–180 ppt) and even hypersaline (80–300 ppt) in coastal lagoons and intertidal pools. Tides are semi-diurnal and oscillate around a nodal point near 19°N with a spring range of 0.6 m in the north and 0.9 m in the southern Red Sea and 1.5–2.5 m in the Gulf of Aden.

However there is no appreciable semi-diurnal tide in the central Red Sea. Strong seasonal changes of up to 0.5 m occur throughout the Red Sea due to monsoon winds, causing a large part of the intertidal zone to be inundated during winter months. These seasonal monsoonal factors must be taken into account when surveying intertidal areas in the central region of the Red Sea and exposed regions such as Socotra, which are subject to periods of cooler upwelling water.

The biota of the Red Sea have been studied extensively since the 1700s and in general the intertidal biodiversity is now relatively well known (FORSSKAL 1775; JONES et al. 1987; OLIVER 1992; SHEPPARD et al. 1992; TURNER et al. 1999). There is sufficient information to establish regional characteristics (JONES et al. 1987) and to allow comparisons between different biotopes (sand, mud, mangrove, saltmarsh, rock), between similar biotopes within the region and different shore levels within a biotope, based on presence and absence of species.

However there is far less information available on quantitative aspects of abundance, biomass and productivity (JONES et al. 1987; SHEPPARD et al. 1992).

2.2 AIMS OF SURVEYS

Now that the intertidal biodiversity within the region is known, most surveys are concerned with quantifying the areas of each biotope within the region. In this way, rarer biotopes (and their biodiversity) can be identified and thus protected. Although few, if any, pristine biotopes still exist, the degree of naturalness and potential for such areas to act as replenishment sources also needs to be established. For conservation objectives it is essential to evaluate the current status of biodiversity and abundance so that natural changes can be distinguished from unnatural anthropomorphic changes or impacts over time and used in integrated environmental assessment (PRICE et al. 1998).

Methodology for intertidal surveys recognises the need for measurement of the physical factors controlling distribution and zonation of biological communities. These factors were identified in the 1960's for rocky (LEWIS 1964) and soft sediment shores (MCINTYRE 1968) and have been incorporated into texts on survey methodology (HOLME & MCINTYRE 1984; BAKER & WOLFF 1987). More recently methodology for tropical biotopes such as mangroves has been considered (ENGLISH et al. 1997). Adaptation of general survey methodology to the region is detailed in BASSON et al. (1977), EDWARDS & HEAD (1987), KRUPP et al. (1996), TURNER et al. (1999) and in numerous research papers (cf. MCCAIN 1984, PRICE & ROBINSON 1993, JONES et al. 1998a).

These authors identify rapid site assessment using key biological species as valuable indicators for distinguishing intertidal biotopes. This methodology concentrates on recording the presence and absence of macrobiota (see Appendices 2.6.1 to 2.6.3) and avoids problems of selective collection of small sized (less than 0.5 mm) organisms. The methodology is relatively inexpensive and with training does not require high levels of expertise; in addition the data collected can be used for ground-truthing of satellite imagery and hence used not only on a local but also at national and regional levels. Data should be stored using Geographical Information Systems (GIS) which can be intercalibrated within the region. Examples of this approach include VOUSDEN (1988), KWARTENG & AL-AJMI (1997) and TURNER et al. (1999).

For evaluation of long-term fluctuations in biotopes, either through natural changes or from anthropomorphic impacts, quantitative monitoring of permanent transects is necessary. This approach, which requires control sites for comparison, has been used successfully within the region to evaluate intertidal recovery after impact (JONES et al. 1998a) and to form the basis for monitoring integrated coastal management plans for the Socotra Islands (TURNER et al. 1999).

Methods for the estimation and quantification of marine productivity from intertidal biotopes are often species specific and utilise a wide range of biochemical and other techniques (IUCN 1987). One of the most useful is the measurement of natural stable carbon and nitrogen isotope ratios throughout the food web (RODELLI et al. 1984). Although studies have been initiated using this technique for Arabian Gulf mudflats (JONES et al. 1998b), they are beyond the scope of the present methodology, which concentrates on survey methods for conservation.

2.3 SURVEY METHODS

These will vary depending on the survey aim and type of intertidal biotope (i.e. soft or hard substrate). For conservation objectives, these will concentrate on the evaluation of the current status of biodiversity and abundance and the distinction between natural and unnatural (human-induced) changes over time. Scales of survey range from local (e.g. bay) to national and regional levels and methodology should allow integration between these levels (cf. PRICE et al. 1998).

2.3.1 Remote Sensing and Geographical Information Systems (GIS)

Although initially expensive, these are becoming the standard approach to medium (island) and large-scale (country, region) intertidal surveys and allow collection and transfer of data on a readily accessible basis. They have the advantage in that, once ground-truthed, all similar biotopes can be classified throughout the region. For details on preparation and usage see KLAUS (1999) and relevant chapters in this manual. Even if these systems are not used, data should be collected as indicated below in a form that may be accessed at a later date for entry into these systems.

2.3.2 Rapid Site Assessment (RSA)

This survey method depends upon the classification of habitats or biotopes by recording the presence and absence of key species together with a description of the physical characteristics of the habitat. Although it is not quantitative the use of key species presence and absence sheets (Appendices 2.6.1 to 2.6.3) not only enable a biotope to be recognised, but also its range and overlap with other biotopes to be ascertained. The survey method is inexpensive, does not require a high level of training, can be operated with a field team of two to three persons, and can supply all the information necessary for ground-truthing of satellite imagery. A further advantage is that additional sheets (Appendix 2.6.4) can be designed to record physical descriptions, human impact and habitat degradation. Examples of the use of these RSA sheets can be found in PRICE (1990), JONES & RICHMOND (1992), JONES et al. (1998a) and TURNER et al. (1999). Physical data appropriate to each habitat type are also collected at the same time and used together with the biological data to classify each biotope (see analysis below).

2.3.3 Species identification

The most appropriate and useful identification guides to biota of the region are given in the section 'Identification Guides and Other Recommended Literature' following the list of references in section 2.5.

2.3.4 Quantitative or permanent monitoring surveys

These are used to collect quantitative data on the abundance of intertidal biota over extended periods before and after anthropomorphic impact (Environmental Impact Assessment EIA), to monitor natural environmental changes, or to evaluate intertidal productivity and links to fisheries. Methods used are habitat specific and are given below for each biotope. These surveys also require collection of physical data and are often conducted seasonally. Examples of such surveys within the region are given by JONES et al. (1987), PRICE et al. (1987), JONES et al. (1996, 1998a) and TURNER et al. (1999).

2.3.5 Data analysis

Records of species presence and absence from the key species sheets compiled for each shore visited may be entered onto a computer database and analysed to determine similarities between sites and shore levels. Most useful methods include Hierarchical Agglomeration (Cluster Analysis), using, for example, Tanimoto Index (PRENA 1996), or diversity indices such as Shannon-Wiener index (ENGLISH et al. 1997). Principle Component Analysis can also be used to separate biotopes or presence and absence of species (PRENA 1996). Physical data can also be analysed, using suitable software programmes such as PRIMER. This can be used to construct cluster dendrograms, to calculate univariate diversity indices, to measure similarity and dissimilarity and to identify the key species responsible for dissimilarity, with estimation of their percentage contribution to dissimilarity. For further information, see CLARKE & WARWICK (1994).

For quantitative surveys where abundance data are required, the minimum sample size needed to estimate diversity must be calculated. This is achieved by plotting the cumulative number of species against increasing sample area until no new species are found (BAKER et al. 1987). Similarity area curves can also be plotted against increases in sample size using Tanimoto Index (presence and absence of species) and Kulczynski Index (abundances) to determine optimum sample size (see PRENA 1996 for worked examples). For a full discussion of comparability and reproducibility and more detailed treatment of quantitative data see BAKER et al. (1987). At least three replicates should be taken at each sampling point to allow for calculation of variability.

2.4 BIOTOPE SPECIFIC METHODOLOGY

2.4.1 Sand beaches

These vary greatly both in physical and biological characteristics, depending upon the degree of exposure to tide and wave action ranging from the 100 m plus dune backed beaches of Socotra to narrow muddy stretches of sand between mangroves and lagoons in the Red Sea.

Physical survey

The exposure index (EI) of MCLACHLAN (1983) is widely used to rank sand beaches. This uses measurement of beach profile, sand grain analysis, organic content, temperature (air and 10 cm below surface), salinity, wave height, width of swash zone and depth of anoxic black zone, plus presence of permanent burrows to determine EI. The beach profile between the tide marks is measured using a surveying level and pole (DALBY 1987) and is related to known tide levels using local tide tables. Sand grain analysis is conducted using sediment samples of 200 g from the top, mid and bottom of the beach and, after washing to remove salt, analysed by weighing the fractions retained in a series of sieves (BUCHANAN, 1984). Organic content is the difference between dry weight of salt free sediment and the weight of this sediment after ashing in a muffle furnace at 450°C for 30 minutes. (Dry weight is determined by drying sediment for 24 h at 60°C). In all cases sediment should be cooled in a desiccator before weighing to prevent uptake of water from the atmosphere. Salinity may be measured using a refractometer (American Optical Co., USA). Temperature and oxygen probes are described in ENGLISH et al. (1997). Examples of the use of these measurements to determine EI are given in MCLACHLAN & ERASMUS (1983) and JONES & PIERPOINT (1997). The position of each beach should be determined using GPS and Site Sheets (Appendix 2.6.4) completed on each beach surveyed.

Biological Survey: RSA

For RSA, the presence and absence sand beach key species list (Appendix 2.6.1) may be used. Observers (two or more) walk on a bearing perpendicular to the shore between the tidemarks. All species encountered are identified and recorded and those difficult to identify are labelled and sent to an expert for identification. Many sand beach inhabitants remain buried during low tide so that burrows should be photographed and dug out to identify burrower and link species to characteristics of burrow. Several of the key species, such as the amphipod *Talorchestia* and isopods *Tylos* and *Eurydice*, are relatively small (1–5 mm) and may only be revealed by sieving sand through a 1 mm mesh at intervals down the beach. Once species are correctly identified, data from key species sheets are entered into the computer and may be analysed as indicated in 2.3.5.

Permanent monitoring or quantitative surveys

Long-term monitoring sites are usually selected as a result of analysis of RSA surveys to reflect natural biodiversity (control) and sites subject to perturbation. For sand beaches, permanent transect lines (PTL) are established from high water spring to low water spring tides perpendicular to the shore. Each PTL should be marked with a post set in concrete at the top of the shore and its position recorded using GPS. Sampling stations should be positioned at four shore levels: littoral fringe (LF), upper eulittoral (UE), lower eulittoral (LE) and sublittoral fringe (SF). These stations are located at tidal levels high water spring (HWS), high water neaps (HWN), low water neaps (LWN) and low water springs (LWS); thus, they will not necessarily be equally spaced, but depend on the shore profile. This is important as beach fauna arrange themselves according to tidal level (see JONES 1986).

Physical data should be collected as outlined in *Physical survey* above. Epibiota are sampled by taking five random quadrats at each station, the quadrat size depending on species abundance. For example ghost crab (*Ocypode*) burrows may require 10 m^2 quadrats to obtain statistically useful densities, whereas fiddler crab (*Uca* sp.) burrows can be surveyed adequately within 1 m^2. Infauna at each station are sampled by taking triplicate 25 x 25 x 15 cm deep cores in the sand and sieving, using 1.0 mm mesh. All material retained should be preserved in 5% formalin in seawater for sorting, identification and counting in the laboratory. On exposed shores where a large particle size is encountered, it may be necessary to first use a 2 mm mesh to remove excess sand. It should be noted that employment of small mesh sizes, such as 0.5 mm, would sample meiofauna, producing abundances of up to 400,000 animals/m^2 (MCCAIN 1984); however macrofaunal biodiversity is sufficient for most conservation surveys. In the laboratory each faunal sample is spread out in a shallow tray, just covered with water, and fauna sorted from residual sediment are identified and counted. Final storage may be in 70% alcohol 30% glycerol solution. Rose Bengal may be used to stain biological material to facilitate its separation from sand.

For food web surveys it will be necessary to use surf plankton nets (COLEMAN & SEAGROVE 1955) and beach seine nets to sample biota migrating in during high tides. Photography and video filming may be useful to estimate bird populations, and correct completion of site sheets (Appendix 2.6.4) will ensure anthropomorphic information is recorded.

2.4.2 Mud flats

Mud flats are usually found in sheltered bays, wadis or harbours protected from wave action, often in open areas below salt marsh or mangrove. They are defined as soft sediment shores where the predominant particle size falls below 64 µm and soil is composed of silt (3.9–62 µm) and clay (less than 3.9 µm). They are often waterlogged and high in organic detritus and subject to microbial decomposition through oxygen reduction (redox) processes.

Physical survey:

Measurement of redox potential (Eh) will assess the potential impact of additional organic input as it provides the existing degree of anoxia (PATRICK & DELAUNE 1977). Eh and pH should be measured onsite by digging a hole 20 cm deep into the mud and pressing the calibrated platinum electrode of a pH/millivoltmeter into the side of the hole 10 cm from the surface. Readings may be corrected by the addition of +244 mV to give Eh (ENGLISH et al. 1997). Temperature should be measured 10 cm below the mud surface, and salinity by placing soil in a syringe with a filter paper covering the tip and squeezing water from the sample onto a refractometer. Soil particle size may be measured after the removal of gravel and sand by the sedimentation technique of BUCHANAN (1984).

Mudflats are often extensive and can exceed 1000 m between the tide marks. To mark the profile and sampling levels it is best to time the incoming tide and hence measure the very shallow profile. While the top levels can usually be reached without problems, mud often becomes softer and deeper towards low tide and may best be sampled by boat on a rising tide (MULDER & ARKEL 1980).

Biological Survey: RSA

Methodology is similar to that adopted for RSAs on sand beaches except that the key species sheet (Appendix 2.6.2) should be used. As most macrofauna of mudflats make permanent burrows, time should be spent photographing burrow types and digging out and identifying occupants so that key species can be recognised from burrows. Binoculars are useful as most species appear on the surface at low tide. The presence and extent of surface microbial mats should also be recorded. Site sheets (Appendix 2.6.4) should also be completed. Where the mud is soft it may be necessary to approach at low tide in a small inflatable dingy, moving up the shore on the rising tide to survey the shore.

Permanent monitoring or quantitative surveys

Methodology is similar to that for sand beaches where the shore is accessible by foot. For deep soft mud, grab or core samples must be taken from a boat operated on the rising tide (Fig 2.1). The van Veen grab takes a sample of approximately 0.1 m^2 and is the lightest of the conventional grabs, as for use in mud it can be constructed of lightweight metals. The corer is made of PVC and commonly has a cross-sectional area of 0.01 m^2 and a length of 1 m. In operation it is thrust or rotated into the sediment to a depth of 15 cm with the top end open; a bung is then fitted to this end to allow the corer to be withdrawn whilst retaining the cored mud. The mud is washed through a 1.0 mm mesh sieve hung over the side of the boat and retained biota preserved in 5% formalin in seawater.

Much of the primary production on mudflats is carried out by microalgae, a mixture of pennate diatoms and Cyanophyta known as microbial mats. If these are to be quantified for food web or other studies it is necessary to remove small areas (5 cm^2) of surface sediment down to 1.5 mm using a microscope cover slip. This sediment is made up in a known volume of seawater, preserved using Lugol's iodine, and cells counted and identified using a haemocytometer slide. Alternatively 25 x 25 cm x 0.5 cm deep cores can be taken and chlorophyll extracted with 90% acetone neutralised with magnesium carbonate over 24 h, centrifuged and the absorption of the supernatant read in a spectrophotometer (details given by BAKER & WOLFF 1987).

As for sand shores tidal immigrants over mudflats can be sampled using seine nets, hadras, or baited traps. Estimation of bird species and populations can be made by direct observation with binoculars, photography and videorecording.

2.4.3 Saltmarsh

Saltmarsh is an area of land bordering the sea, more or less covered in vegetation and subject to periodic inundation by the tide. Saltmarsh occurs throughout the Red Sea, declining towards the more tropical south, and occupies the zone above the mangroves. It is composed of halophytic plants and marks the landward extension of most marine biota. Due to high evaporation rates soil salinity may be very high and any fresh water waste run off will cause landward extension of marshes. The halophytes act to stabilise sediment so that tidal influences form a network of channels and creeks running between patches of vegetation. They are highly productive, shelter abundant bird populations and are of significance for conservation.

Physical survey

Extensive salt marshes require photographic aerial surveys to map the extent of vegetation and channel systems. Profiling can be conducted using a surveying level and pole but, where marshes are extensive, the use of the incoming tide to mark height above chart datum is usually adequate. Collection of data on temperature, salinity, pH, Eh, sediment particle size and organic content is similar to that for mudflats (2.4.2).

Biological survey: RSA

Methodology is similar to that adopted for RSAs on sand, except that, as for mud shores, the key species sheet (Appendix 2.6.2) should be used. Only the biota listed under the littoral fringe will be found. However, depending on freshwater input, a range of up to 20 species of saltmarsh plants such as *Phragmites* and *Typha* sp. may occur and reference should be made to HALWAGY et al. (1986), ORME (1982) and taxonomic descriptions of COLLENETTE (1985). Site sheets (Appendix 2.6.4) should be completed.

Permanent monitoring or quantitative surveys

Permanent transect lines may be set up running perpendicular across the marsh and vegetation quantified using 1 m^2 quadrats (5 replicates) at intervals across the marsh. Depending on plant size, density (number of plants of each species per quadrat), or cover (area of each species per quadrat when viewed from above), estimates can be taken to quantify species and abundance. However care is needed in designing sample strategy if large plants such as *Phragmites* dominate (DALBY 1987). Similar 1 m^2 quadrats may also be used for larger *Sesarma* or *Uca* crab burrows and gastropods such as *Cerithidea*; for smaller infauna, estimates should use the 25 x 25 x 15 cm deep sediment samples sieved through a 1.0 mm mesh (*Biological Survey: RSA*). Similar methods to those used for mudflats (2.4.2) can be used to estimate bird cover.

2.4.4 Mangroves

Although these occur throughout the region they are no more than stunted *Avicennia* bushes in the northern Red Sea and only *Avicennia* and *Rhizophora mucronata* are common in the south, with a total area regionally of 450–500 km^2 (SHEPPARD et al. 1992). They grow between HWS and HWN tide levels and, although usually associated with soft mud, may occur on hard bottom substrates behind coral reefs on islands. Best development is seen in the southern Red Sea where trees reach 5–7 m in height and stands may be 100–500 m wide (PRICE et al. 1987).

Physical survey

As the sediments usually consist of soft mud, methods of analysis are those used for mudflats (2.4.2). Where hard substrate mangroves exist sediments may be sandier and methods for sand grain size analysis may apply (2.4.1). Detailed data analysis is given in ENGLISH et al. (1997), while an example is given in AL-KHAYAT & JONES (1999).

Biological survey: RSA

Similar methodology applies to that used for other soft sediment shores, except for the use of Appendix 2.6.2 key species sheet using littoral fringe and upper eulittoral species. All mangrove species likely to occur within the region are illustrated in RICHMOND (1997). It should be noted that within the region it is likely that species from other key species sheets (Appendices 2.6.1 to 2.6.3) may occur. These should be recorded for mixed communities, including some rocky shore species settled on mangrove trunks and pneumatophores and sand dwellers, which may coexist (PRICE et al. 1987).

Permanent monitoring or quantitative surveys

Methods of quantifying abundance and biomass of mangrove trees are described in ENGLISH et al. (1997), but most are not applicable to the sparse stands found within the region. Where possible, aerial photography should be used to determine the extent of forest (in many cases this will allow tree counts to be made). For much of the Red Sea region it is possible to measure height and girth at breast height for trees individually along a transect vertical to the shore. If stands are too abundant for this procedure then the Transect Line Plot method of ENGLISH et al. (1997) is recommended. For other biota, such as microbial mats and macroalgae attached to roots, methods discussed in 2.4.2 and 2.4.5 should be adopted. For macrofauna, 1 m^2 quadrat (5 replicates) counts of burrows, initially identified by digging up their inhabitants, will allow quantification; standard 25 x 25 x 15 cm deep sieved sediment samples are used for smaller infauna. Where mud is consolidated or sticky it should be transferred to a bucket of water and broken down gently by hand, before sieving through a 1 mm sieve. Smaller quadrats (10 x 10 cm), with five replicates, can be used to quantify sessile fauna such as barnacles and mangrove oysters (*Saccostrea*)

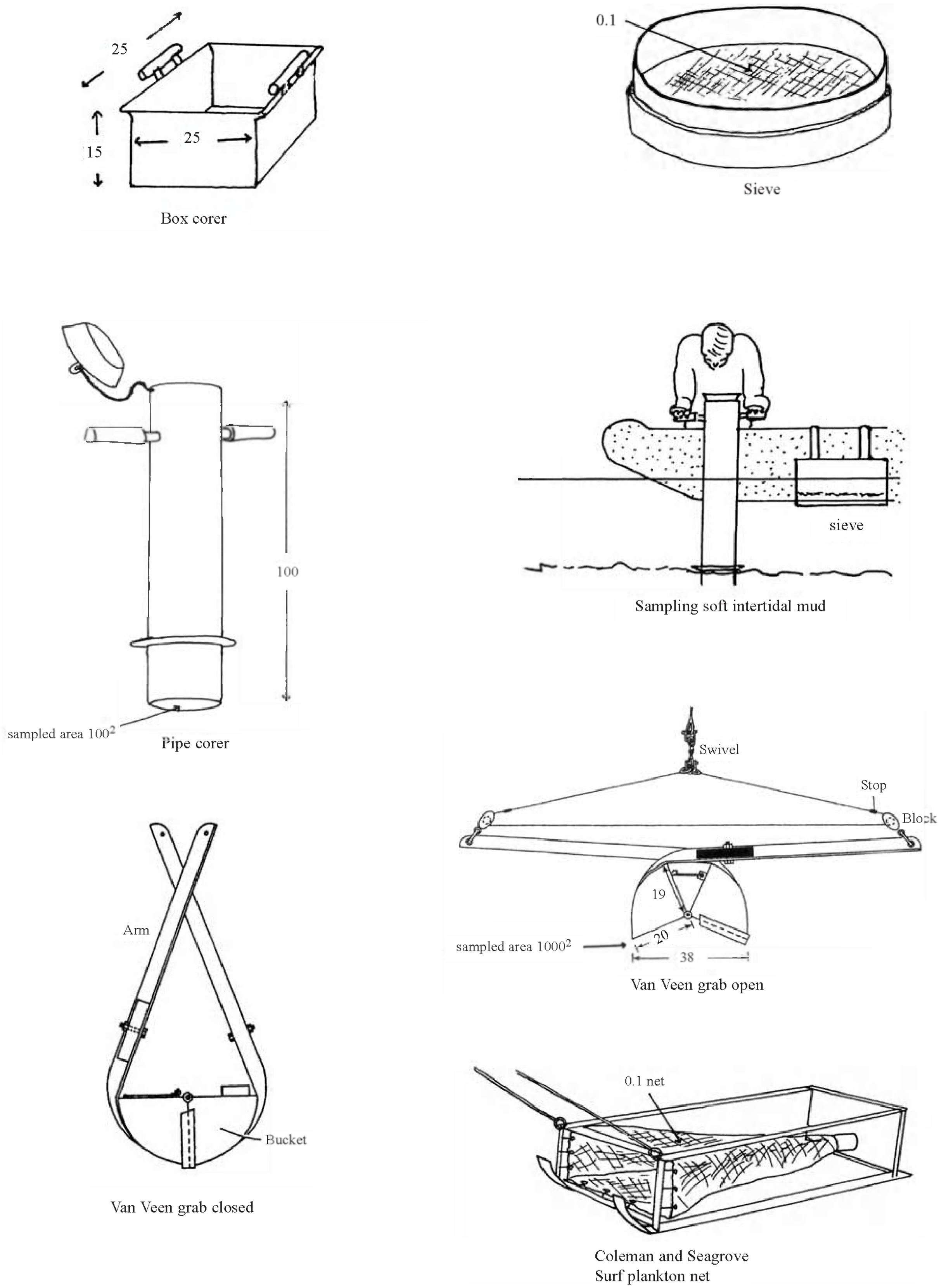

Figure 2.1 Intertidal sampling gear, all measurements in centimetres

attached to trunks and pneumatophores of mangrove trees. Birds can be estimated by direct counts, photography and videorecording. Surveys for mangrove biota, together with analyses, are presented in AL-KHAYAT & JONES (1999).

2.4.5 Rocky shores

These range from flat terraces extending out to fringing reefs, often strewn with boulders, to 1000 m high vertical cliffs on the coast of Socotra. The former are described by FISHELSON (1971) in the northern Red Sea, JONES et al. (1987) in the central Red Sea, BARRATT et al. (1987) for the coast of Yemen and TURNER et al. (1999) for the Socotra Islands. A strong pattern of biotic vertical zonation is present throughout the region, although this may be modified seasonally by changing tide levels in the central Red Sea (JONES et al. 1987) and by cold water upwelling on the southern coast of Oman and Yemen (BARRATT et al. 1986) and Socotra (TURNER et al. 1999).

Physical survey

Profiles for reef flats may be measured using a conventional surveying level and pole and for vertical cliffs simply using a measuring tape. However, care must be taken when assigning biological zones to tidal heights as exposure to wave action, shore aspect and insolation can drastically expand or contract bands of biotic zonation. Shelter from the sun under wave-cut notches in cliffs, or under boulders, will allow lower shore species to colonise higher positions. Hence it is important to record shade and open shore surface rock temperatures, together with temperature and salinity in pools at different levels on the shore. Lagoons, pools and other irregularities often trap sediments and these should be recorded and sampled (see sections 2.4.1 and 2.4.2). If measurement of 'exposure' is required see BAKER & WOLFF (1987). For discussion on the interaction between physical and biological factors controlling zonation patterns see JONES et al. (1987).

Biological Survey: RSA

Methodology is similar to that used on soft substrate shores above, except that the key species sheet for rocky shores (Appendix 2.6.3) should be used. Strong patterns of vertical zonation are to be expected. There has been considerable revision of molluscs recently and BOSCH et al. (1995) and OLIVER (1992) are recommended for gastropod and bivalve identification respectively. Other taxa can generally be found in RICHMOND (1997). Presence of tar and other pollutants covering rocks should be noted and recorded on Appendix 2.6.4 sheets.

Permanent monitoring or quantitative surveys

Due to the visually obvious nature of rocky shore biota, many methods have been devised to measure their abundance and change over time; for a review see BAKER & WOLFF (1987). Problems encountered include the range in size and type of organism (e.g. barnacles and large *Sargassum* macroalgae), topography of the shore, physical danger of wave action on the lower shore and seasonal changes within the region (see above).

Once an RSA has been completed, vertical biological zones on a shore will have been established. For long-term monitoring a concrete marker can be placed at the top of the shore, and the centre of each biological zone marked by drilling a hole in the rock or hammering in a metal peg. Distances between sample sites can be established using a tape measure. In each biological zone (see Appendix 2.6.3) random 1 m^2 quadrats can be used (5 replicates) to estimate abundance of sessile biota. Flexibility is needed depending on the size and abundance of individual species, so that barnacles may be counted using smaller 10 x 10 cm quadrats, whereas macroalgae or sponges may require a percentage cover estimate. On exposed shores many species may shelter under stones, so it may be necessary to conduct counts/percentage cover for the area of the underside of stones at each level. Providing a similar sampling strategy is operated across the whole shore, data will be valid.

Photographic records of permanent quadrats are particularly valuable where long-term changes are to be monitored. Transparencies taken over time can be overlaid to visualise changes. Hewlett-Packard computer plotter and graphics programmes are available that use a digitised pen to count species, provide statistics and draw histograms directly from the photographic transparencies.

To assess seasonal succession on rocky shores, areas 1 m^2 can be cleared of all biota and monthly estimates of recolonisation made. Similarly, settlement plates (tiles or slates) secured at different levels on the shore and removed at intervals will establish patterns of colonisation. This approach is particularly relevant for assessment of recovery after impact (JONES et al. 1996).

2.4.6 Specialised biotopes

Mixed biotopes

The commonest of these are combinations of sand, mud and rock coexisting due to shore topography. Throughout the Red Sea sand beaches often give way to rock flats towards low tide. These may have a thin covering of sand or simply consist of exposed rock. BASSON et al. (1977) and JONES et al. (1996) describe these mixed communities in detail. Methodology described above (2.4.1, 2, 3, 4, 5) should be used as appropriate to substrate type. RSA surveys will distinguish the differing biological communities and appropriate quantitative methods (see above) can then be applied.

Sabkha, metahaline and hypersaline pools

These environments are found in flat coastal plains, particularly to the north of the Red Sea, and as they are only intermittently inundated by the sea are outside the present remit. ERLICH & DOR (1985) describe the flora while POR (1984, 1985) reviews the fauna of these biotopes.

Artificial structures

These comprise piers, marinas and harbours constructed throughout the region. In most cases, these simply represent vertical or sloping rock shores of varying exposure to wave action and physical and biological survey methods are appropriate. Where harbours dry at low tide, sands and muds may be exposed and these may be surveyed using methods detailed for sand and mud shores above. BASSON et al. (1977) give detailed species lists and zonation patterns for artificial structures.

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APPENDIX 2.6.1 Key species presence or absence for sandy shores of the Red Sea and Gulf of Aden.

	P/A	R	O	C	A	D
LITTORAL FRINGE						
Coenobita scaevola						
Ocypode saratan						
Ocypode cordimana						
Tylos exiguus						
Talorchestia martensi						
UPPER EULITTORAL						
Eurydice arabica						
Excirolana orientalis						
Uca inversa inversa						
Uca lactea albimanus						
Serenella leachii						
Macrophthalmus depressus						
LOWER EULITTORAL						
Hippa picta						
Hippa celaena						
Oliva bulbosa						
Nassarius clathratus						
Macrophthalmus depressus						
SUBLITTORAL FRINGE						
Echinodiscus auritus						
Holothuria arenicola						
Calappa hepatica						
Thalamita savignyi						
Halodule uninervis						
Astropecten polycanthus						
Thalassodendron ciliatum						

P/A, present/absent; R, rare; O, occasional; C, common; A, abundant; D, dominant

APPENDIX 2.6.2 Key species presence or absence for saltmarsh, mangrove and muddy shores of the Red Sea and Gulf of Aden.

	P/A	R	O	C	A	D
LITTORAL FRINGE						
Microbial mats (Cyanophyta)						
Suaeda monoica						
Zygophyllum qartarense						
Arthrocnenum macrostachyum						
Aeluropus/Juncus						
Avicenna marina						
Rhizophora mucronata						
Uca inversa						
Dotilla sulcata						
Littorina scabra						
Serenella leachii						
UPPER EULITTORAL						
Uca tetragonon						
Uca lactea albimana						
Metapograpsus messor						
Pirinella conica						
Cerithidea cingulata						
Periophthalmus koelreuteri						
Avicennia marina						
Rhizophora mucronata						
LOWER EULITTORAL						
Potamides conicus						
Macrophthalmus depressus						
Pinna bicolor						
SUBLITTORAL FRINGE						
Scylla serrata						
Portunus pelagicus						
Halophila ovalis						
Halodule uninervis						

P/A, present/absent; R, rare; O, occasional; C, common; A, abundant; D, dominant

APPENDIX 2.6.3 Key species presence or absence for rocky shores of the Red Sea and Gulf of Aden.

	P/A	R	O	C	A	D
LITTORAL						
Nodolittorina natalensis						
Planaxis sulcatus						
Acanthopleura vaillantii						
Ligia pigmenta						
Chthamalus sp.						
Chiton peregrinus						
Grapsus albolineatus						
UPPER EULITTORAL						
Nerita undata						
Nerita polita orbignyana						
Cronia konkanensis						
Thais savignyi						
Metapograpsus messor/thukuhar						
Cellana rota						
Balanus amphitrite						
Tetraclita squamosa						
Enteromorpha sp.						
LOWER EULITTORAL						
Nerita albicilla						
Morula granulata						
Laurencia papillosa						
Saccostrea cucullata						
Ophiocoma scolopendrina						
Echinometra mathaei						
SUBTIDAL FRINGE						
Zoanthus natalensis						
Echinometra mathaei						
Sargassum sp.						
Turbinaria sp.						
Colpomenia sinuosa						
Corals						

P/A, present/absent; R, rare, O, occasional; C, common; A, abundant; D, dominant

APPENDIX 2.6.4 Site Information.

Latitude	Longitude	Source	Nearest name on map/chart	Sector Code	
Researcher	Details of Location			Date Code	

21 PROFILE	m m				
1	Mangroves				FLORA
2	Seagrass				
3	Halophytes				
4	Algae				
5	Freshwater vegetation				
6	Other				
7	Reefs and corals				FAUNA
8	Birds				
9	Turtles				
10	Mammals				
11	Fish				
12	Invertebrates				
13	Other				
14	Construction				IMPACTS
15	Fishing / Collecting				
16	Pollution				
17	Other				
18	Oceanography				OTHER
19	Meteorology				
20	Other				
Photographic Record					

3

CORALS AND CORAL COMMUNITIES

3.1 INTRODUCTION

Since the 1960s, and in parallel with increasing levels of human impact, major advances have been made in the survey of coral reefs (see e.g. STODDART & YONGE 1971; LOYA 1972, 1978; STODDART & JOHANNES 1978; KENCHINGTON 1978; DAHL 1981; DONE 1981, 1982; WEINBERG 1981; DODGE et al. 1982; ORMOND et al. 1984a; SHEPPARD & SHEPPARD 1985; BROWN 1986; DEVANTIER 1986; HATCHER et al. 1989; ARONSON et al. 1994; ENGLISH et al. 1997; DEVANTIER et al. 1998). These and many other authors have developed a wide variety of field and analytical methods for reef surveys, most of which have been restricted in their application to specific geographical regions or biogeographic provinces. Although useful in their local areas, the application of different methods has limited the broadscale (national, regional or global) comparability of results. This has meant that the understanding of regional and global trends in the status of coral reefs has been limited (CONNELL 1997).

The application of different methods in different areas has also limited the capacity of reef management agencies to communicate the recent widespread deterioration of reefs to governments and international conservation agencies (BROWN 1987; WILKINSON 1992; GINSBURG 1994).

To facilitate national and regional comparisons, reef survey methods should follow a standard protocol, as much as is feasible, given local and national logistic capacities and other constraints. Such methods should be as simple, quick and inexpensive as practicable, and be equally applicable in nations with different levels of finance, human capacity and expertise (ARONSON et al. 1994). The application of these criteria has culminated in several regional reef assessment programmes, including CARICOMP (OGDEN et al. 1997), the ASEAN–Australia Living Coastal Resources Project (CHOU & WILKINSON 1992), Reef Check (HODGSON 1999) and the Global Coral Reef Monitoring Network (GCRMN, WILKINSON 2000). These programmes have each produced status reports that have proven valuable in raising awareness at both governmental and intergovernmental levels.

In developing a standard protocol of research methods for coral reefs, the rationale and context of the methods should be clear and the methods prioritised to address key research and management questions. To this end, this chapter briefly reviews reef research in the RSGA region, focusing on the study of corals and coral communities. Rather than covering the broad field of coral reef studies in general, this chapter provides an overview of the rationale, advantages and disadvantages of various methods for coral reef management-related research. Following consultation with national representatives of the PERSGA expert working-group, the chapter describes a minimum set of methods for site description and survey of benthic cover and coral biodiversity. Recommendations for training, quality assurance, data archival, analysis and presentation, training materials, useful references and a list of relevant world wide web addresses, are provided.

REEF RESEARCH IN ARABIA

The RSGA region has a long history of coral reef research, including some of the earliest taxonomic work ever undertaken (e.g. FORSSKAL 1775; EHRENBERG 1834; MILNE EDWARDS & HAIME 1860). Following these early studies, and since the beginning of modern reef studies in the 1960s, the Red Sea (particularly its northern area) has received a great deal of scientific attention (reviews by MERGNER 1984 and SHEPPARD et al. 1992). These workers have used a variety of methods to investigate taxonomy, biodiversity, biology, demography and ecology of corals and other biota and the environmental properties of the ecosystem. By contrast, reefs and coral communities of the Gulf of Aden have been studied less, being largely unknown until recently (SHEPPARD et al. 1992; MCCLANAHAN & OBURA 1997; KEMP & BENZONI 2000; DEVANTIER & HARIRI in press).

The following brief review outlines various methods recently employed in the region, from the broad-scale to the fine-scale. Broad-scale studies have included habitat mapping of the central-northern Saudi Arabian Red Sea using high definition colour aerial photographs (NCWCD–JICA 2000), and Socotra Islands Group using LANDSAT satellite imagery (TURNER et al. 1999). Other applications of remote-sensed information have included use of broadscale sea surface temperature analyses provided by NOAA/NESDIS (GOREAU & HAYES 1994; GOREAU et al. 1997; STRONG et al. 1997, 1998). These images have been used in the interpretation of coral reef bleaching in the Saudi Arabian Red Sea, Yemeni Socotra Islands and Gulf of Aden (DEVANTIER & HARIRI in press; DEVANTIER et al. in press a,b). All the desk studies relied on extensive 'ground-truthing', generally using rapid ecological site assessments (REA).

REA has been used in the RSGA region for reconnaissance of reef types and condition, estimates of coral cover and counts of organisms such as crown-of-thorns starfish, *Acanthaster planci*, turtles or marine mammals (see e.g. ORMOND et al. 1984a–c; MACALISTER ELLIOT & Partners 1996; WATT 1996; KEMP 1998; PRICE et al. 1998; TURAK & BRODIE 1999; DEVANTIER et al. 2000b). Most of these surveys used semi-quantitative ordinal ranked categories to describe the habitats, flora and fauna, abundances of biological resources, human uses and impacts. Usually physical features, shore profiles and environmental parameters were also recorded.

More geographically restricted quantitative studies using line transects have included assessments of coral cover and community types in Egypt (RIEGL & VELIMIROV 1994; RIEGL & PILLAR 1999), Saudi Arabia (ROUPHAEL & AL YAMI 2000; DEVANTIER et al. 2000b) and Yemen (TURAK & BRODIE 1999; KEMP & BENZONI 2000; DEVANTIER et al. in press b).

Community composition data have been recorded at various taxonomic levels, from ‘lifeform’ to species. Assessment of recovery following ship grounding in the Egyptian Red Sea is being undertaken using video transects and coral settlement plates (S. Clarke, S. Field, pers. comm.). Other applications of video transects in the Arabian region include the assessment of the effects of the Gulf War and coral bleaching on coral communities of the Saudi Arabian area of the Arabian Gulf (VOGT 1996; VOGT & AL SHAIKH in press).

Considerable taxonomic and biodiversity research has also been undertaken in the region. Comprehensive recent studies on corals, including species from the RSGA region, have been conducted by SCHEER & PILLAI (1983), HEAD (1980, 1983), SHEPPARD & SHEPPARD (1985, 1991), VERON (1986, 1993, 2000), HOEKSEMA (1989), TURAK & BRODIE (1999), WALLACE (1999) and DEVANTIER et al. (2000b). Most of these studies have employed variations of a similar field method, i.e. timed scuba-swim searches.

3.2 METHODOLOGY

A minimum set of field and analytical methods for coral reef research in the Red Sea and Gulf of Aden are presented below, grouped under three main headings:

- Site description – rapid assessment
- Benthic cover and abundance of selected taxa – line and belt transects (Reef Check, Lifeforms or Video)
- Biodiversity assessment (timed scuba-swim searches).

Most of these methods are used widely in the Indo-Pacific, as part of Reef Check and the GCRMN, and thus provide an additional level of comparison outside the RSGA region. The methods range from simple and inexpensive to the more complex and costly. Although the primary purpose of the present chapter is to describe a standard set of coral survey methods, most of these methods are also applied during subsequent *monitoring*, and thus some of the considerations discussed below have relevance to both surveys and monitoring. Prior to conducting a coral reef survey, several general considerations need to be addressed.

3.2.1 Sampling

Design and replication

A standard survey design for the RSGA region requires consideration of the spatial scales of interest (Figure 3.1). Ideally such spatial scales are nested to include:

- Replicate samples within a depth range
- One to several depth ranges within a site
- Replicate sites within a reef
- Reefs within a prescribed area or of a particular type
- Areas or reef types within a particular country
- Countries within the region.

Stratified sampling designs should provide information on reef status at various spatial (local, national and regional) and temporal (annual, decadal) scales (Figure 3.1). Within each of the spatial scales, adequate levels of replication are essential for the statistical description of status and detection of differences among sites (*survey*) and of changes that may occur over time (*monitoring*). Ideally, the level of replication should be based on the results of pilot studies that identify the major sources and levels of variation, and the likely statistical power of the sampling design to detect differences (ENGLISH et al. 1997; OXLEY 1997; SHEPPARD 1999a).

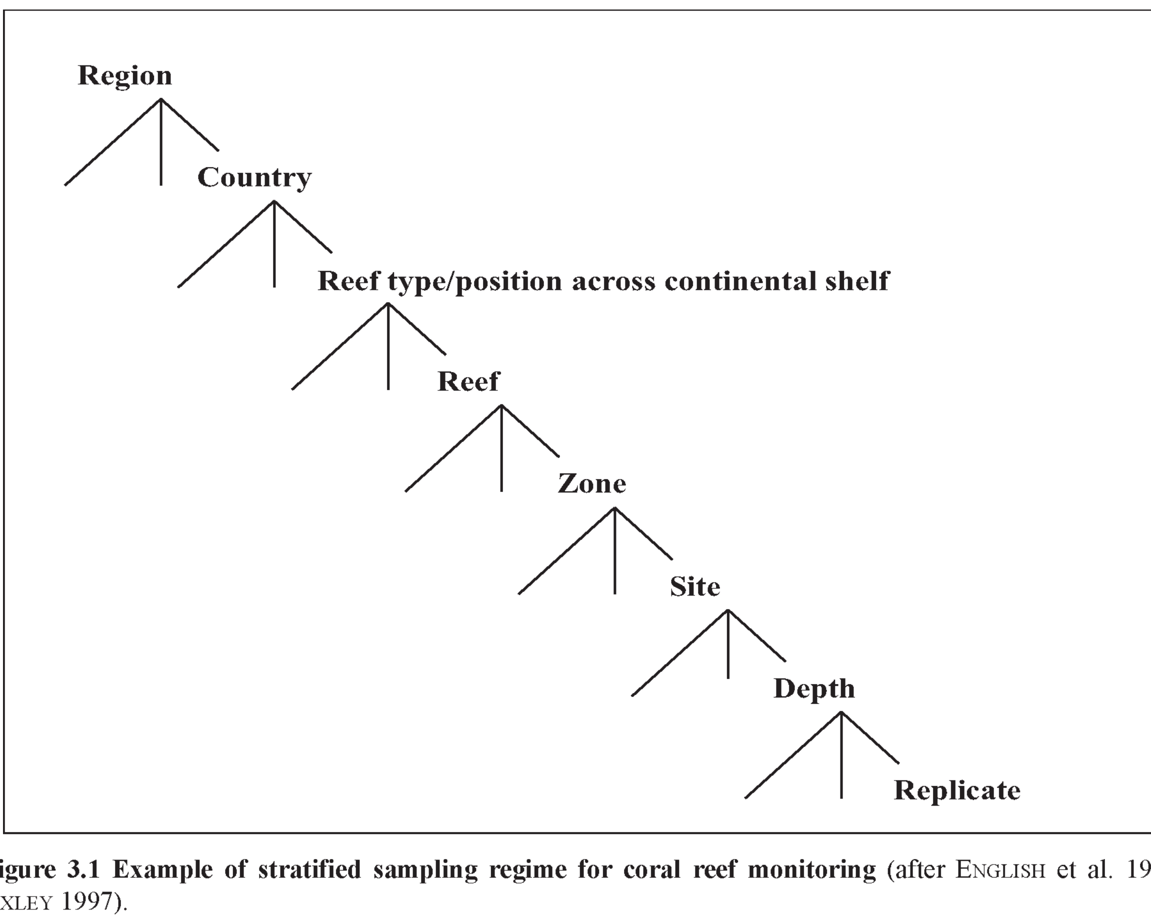

Figure 3.1 Example of stratified sampling regime for coral reef monitoring (after ENGLISH et al. 1997, OXLEY 1997).

For ease of statistical analysis, the sampling design should have balanced levels of replication for:

- Depths within sites – e.g. 3 to 5 transects at one or two depths
- Sites within reefs – at least two sites in each of the different areas (e.g. fore reef, back reef) per reef
- Reefs within reef types – e.g. fringing, patch, barrier, atoll.

For most of the core methods recommended here, pilot studies have determined appropriate levels of within-site replication:

- Reef Check line transects – 4 x 20 m long replicate 'segments' (transects) at each of two depths at each site (HODGSON 1999)
- Lifeform line transects – 5 x 20 m long replicate transects at each of two depths per site (ENGLISH et al. 1997)
- Reef Check belt transects (abundance of selected invertebrates and fishes) – 4 x 100 m^2 (5 m wide x 20 m long) replicate transects at each of two depths per site, centred on the line transects (HODGSON 1999)
- Video belt transects – 5 x 50 m long replicate transects at one or two depths per site (OLIVER et al. 1995; SWEATMAN et al. 1998)
- Biodiversity scuba-swim searches – 3 x 50 minute timed swims at one or two depths per site.

The level of replication at the site level on individual reefs is related to reef geomorphology and exposure and to logistical constraints. Ideally, at least two sites should be surveyed in each exposure regime (e.g. fore reef, back reef) on each reef. Levels of replication at the reef level depend on the types of reefs present, whether fringing, patch, barrier or atoll.

3.2.2 Location of Survey Sites

There are several key criteria that need to be met:

Ease of relocation

Sites should be easy to find on the next survey/monitoring occasion, using maps, navigation charts, landmarks, compass bearings and portable Global Positioning System (GPS) units.

Accessibility

Sites should be easily accessible, based on a realistic assessment of logistic and budgetary constraints, weather and exposure to prevailing sea conditions.

Representativeness – uniqueness

As much as is practicable given logistic constraints, sites should be representative of the different reef types, biotopes and community types present. Similarities and variety in habitat and environmental attributes, known histories of the sites including effects of disturbance, likely future disturbances and any zoning-management implications in terms of marine protected areas (MPAs) all need to be considered in site selection.

Selection can be aided by initial synoptic surveys using manta-tow or similar methods (ENGLISH et al. 1997). Although not recommended here as a core survey method, manta-tow provides a rapid, inexpensive means of assessing reef condition, including the distribution, extent and status of habitats. It is a standard field method of REA, employed and recommended by the GCRMN. The method requires little technical field support, making it useful for isolated locations, and has been employed in many reef regions since the 1970s (e.g. KENCHINGTON 1978; OLIVER et al. 1995; SWEATMAN et al. 1998).

Manta-tow requires good field conditions to be most effective, with water clarity of more than 10 m, clear skies and low cloud cover. Trained observers are towed slowly around the reef of interest behind a small motor boat, at a set speed. Each individual manta-tow is of set duration (2 min.). The boat then stops and the surveyor records a set of standard observational data onto waterproof data sheets (e.g. visual estimates of coral cover, counts of crown-of-thorns starfish). The precise geographical position of the start and finish of each tow is recorded using portable GPS, for ease of relocation. Manta-tow can be used to select sites for more detailed quantitative survey, in terms of their representativeness – uniqueness and status.

Present status

Sites should cover the range of different conditions in terms of disturbance, from recently impacted to pristine, rather than concentrating only on reefs in good condition. This is not to downplay the importance of surveying sites in excellent or pristine condition. SHEPPARD (1995) provides a useful discussion of the global importance of surveying such sites and of the ‘shifting base-line syndrome’.

Depth

As far as practicable, sites should be within standard depth ranges. The two standard depth ranges for benthic cover surveys are 2–6 m and 7–12 m, consistent with the Reef Check and GCRMN recommendations for a depth stratified sampling design. It is important that samples (replicate transects) within each of these two depth ranges are positioned haphazardly or randomly within homogeneous habitats, rather than across different habitats. Recommended depth ranges for biodiversity surveys of shallow and deep coral communities depend on local depth-related shifts in community structure, with prior surveys in the RSGA region using < 7 m and > 7 m respectively (e.g. DEVANTIER et al. 2000b).

Where particular site characteristics preclude the use of the standard depth regimes (e.g. too shallow, different coral community depth distributions or geo-morphological characteristics etc.), then the precise depth range selected is at the discretion of the local survey team. For example, some shallow reefs in the RSGA region are less than 7 m in depth, with major changes in cover and community structure occurring at ca. 3 m deep. In such circumstances, shallow sites should be in the 1–3 m depth range and deep sites from 4–6 m deep. The depths selected at all sites, whether following the standard recommendations or with site-specific alterations, should always be clearly documented on the field data sheets.

If two depth ranges are to be surveyed in a single dive, deeper surveys should always be conducted first, within conservative dive-time limits in accordance with safe diving practice. In particular, great care regarding dive times should be taken at any sites below 10 m deep, especially where repetitive diving over several days is taking place. Careful adherence to conservative diving tables and/or dive computers is mandatory during all diving operations.

3.2.3 Seasonality

As much as is practicable given logistic constraints, all sites should be surveyed within a single season, to avoid or minimize inter-seasonal effects, particularly the rapid growth of macroalgae in some reef areas.

3.2.4 Team Size, Training and Quality Assurance

National coral reef survey teams should consist of a minimum of three trained personnel. This allows for rotation among the three team members to form a dive team of two with one person to handle the boat. Larger teams clearly can accomplish more field and laboratory work, and national teams should be expanded as funding and resources permit.

It is most important that all field workers are consistent in their observations, to minimize the likelihood of introducing bias in recording data. OLIVER et al. (1995) identify five potential sources of bias, error and imprecision in field data:

- Recording – transcription
- Instruments
- Measurement bias
- Sampling bias
- Observer bias.

It is most important that a system of quality assurance is developed, to minimize errors in the data collected. This is achieved through initial training courses in the field methods, followed with regular refresher courses. Where logistics permit, it is highly advantageous to enter field data directly onto a portable computer in the field at the end of each day. This provides the opportunity to check for any obvious errors immediately. Various statistical tests are available to check for different forms of bias in the field data (see ENGLISH et al. 1997; OXLEY 1997; DEVANTIER et al. 1999).

3.2.5 Logistics and Equipment

National coral reef survey teams will require the following equipment:

Essential

- Access to reliable land and sea transport
- Field camping and cooking equipment
- Capacity to determine precise field locations – maps, navigation charts, aerial photographs, compass, portable GPS, binoculars
- Access to scuba-diving equipment – portable dive compressor, dive tanks, regulators (with spare second-stage ‘octopus’, depth-gauge, tank pressure gauge, underwater thermometer), wetsuits, masks, fins, snorkels, dive knives, dive bags and underwater carry bags, replacement spares and repair kits
- Waterproof watches
- Safety devices – medical kit, emergency training (e.g. resuscitation), dive tables, medical emergency plan including contact with nearest hospital and recompression chamber, inflatable life-vests, flares, signalling mirror, orange ‘V sheet’, waterproof torches, water storage containers
- Field data sheets and boards
- Tide tables
- Transect tape measures – plastic or fibreglass for underwater use (3 x 100 m tapes, 10 x 20 m tapes)

- Geological pick or equivalent hammer for collecting coral and other specimen samples
- Sample preservatives and storage bags
- Computer with spreadsheet and database programmes.

Optional

- 4-wheel drive 'utility' car for land transport of personnel and equipment
- Seaworthy boat with two motors, oars and safety equipment for sea transport
- Diving computers
- Underwater stills camera (e.g. Nikonos V or digital equivalent) with close-up, standard (28 mm and/or 35 mm) and wide-angle (15 mm or 20 mm) lenses and strobe flashlight
- Video camera (digital Hi–8) with underwater housing and videotapes
- 10 x 50 m transect tapes for video transects
- Portable computer for field data entry
- Steel pegs and heavy hammer for permanently marking transects
- Safety devices – portable oxygen-supply kit, radio distress beacon, hand-held radios or satellite telephone
- Membership of Diver Alert Network (DAN) for medical emergency evacuation.

3.3 SELECTED METHODS

3.3.1 Site Description

Various descriptive types of information are recorded using a rapid assessment method on standard site description data sheets, to aid the understanding of the present status of the site and for ease of relocation in future surveys. For the survey of coral reefs, these include:

- Reef name or other identifier (number etc.)
- Sample identity code (ID) – a unique site descriptor number for each site that is placed on all data sheets used at a particular site, linking site description with benthic cover and biodiversity survey results (see later)
- Location – GPS position, compass bearings, maps etc.
- Survey observers' names
- Reef type – e.g. fringing, patch, barrier, atoll
- Date

Reef type	Reef development	Reef slope	Visibility	Exposure to prevailing wind & waves
Fringing	1. Extensive (flat > 50 m width)	Average angle to the horizontal in increments of 10 degrees	Horizontal using metric tape or vertical using Secchi disc	1. Sheltered
Patch	2. Moderate (flat < 50 m width)			2. Semi-sheltered
Barrier	3. Incipient (no reef flat but some accretion)			3. Semi-exposed
Atoll	4. Coral community (coral cover > 10% growing directly on non-reefal rock or sand: and see chapter 5 by Kemp)			4. Exposed

Table 3.1 Attributes assessed during site description for coral reefs.

- Time of survey
- Tide
- Distance to nearest town
- Presence of human litter or rubbish or fishing gear above and/or below water
- Weather conditions – approximate amount of cloud cover, wind speed
- Level of reef development (as ranks, see later)
- Degree of exposure to waves (as ranks, see later)
- Average angle of reef slope (nearest 10 degrees to horizontal)
- Underwater visibility
- Present status – any recent impacts
- Type(s) of survey method used: Reef Check, Lifeform, Video, Biodiversity
- Anecdotal information – local knowledge about the site
- Other observations and remarks.

Following the underwater surveys, additional site description information is recorded:

- The presence of any unique or outstanding biological features, such as particularly large corals or unusual community compositions
- The presence of bleached corals (partial or total loss of pigments on living corals)
- The presence of coral predators and other cause(s) of coral mortality.

Recommended alpha-numeric site descriptor codes include the first two alphabet initials of each country, followed by a hyphen, then three numerals for the site number and then an ***a*** or ***b*** for deep or shallow depths. Thus, examples for the first site surveyed in each country are:

- Djibouti – DJ–001a
- Egypt – EG–001a
- Jordan – JO–001a
- Saudi Arabia – SA–001a
- Somalia – SO–001a
- Sudan – SU–001a
- Yemen – YE–001a

If two or more teams are working within a single country, as for example could occur between the Red Sea, Gulf of Aden and Socotra coasts of Yemen, then care must be taken to allocate unique site codes.

Examples of the ranks used in several of the site description categories above are provided in Table 3.1. An example of the Subtidal Site Description data sheet is provided in Table 3.2 and in Appendix 3.7.1. Reef Check also provides a standard Site Description sheet (Appendix 3.7.2), which should be completed in addition to the Subtidal Site Description sheet at all sites where the Reef Check methods are used.

Equipment: Maps, navigation charts, aerial photos, tide tables, portable GPS, compass, binoculars, field data sheets and board.

SITE No: SU-001a	Reef Name: Persga Bay	Weather: Fine		Date: 15 May 2001	Obs:
Lat:	Depth: 8 – 11 m	Tide: high		Distance to nearest town: 10 km	
Long:	Visibility:	Time:	Human litter: None		

Survey methods:	Reef Check: yes	Lifeform:	Video:	Biodiversity: yes

Map (show N point and scale)	Profile (show vertical and horizontal distance)

Reef type				Reef development				Other substrata			Exposure			
Fring.	Patch	Barrier	Atoll	Major	Moderate	Incipient	Coral comm.				Sheltered	Semi-shelt.	Semi-expos.	Exposed
yes					yes							yes		

Total Bleaching	Partial Bleaching	Slope angle	COT Stars	*Drupella*							
	yes	20		yes							

Notes:

Some partial bleaching, mostly on branching corals, and also low numbers of *Drupella* snails feeding on *Acropora* spp.

Several large massive *Porites* corals > 3 m in diameter.

No signs of human rubbish or fishing lines, nets etc. No signs of anchor damage.

Table 3.2 Example of partially completed coral reef site description data sheet for a fictitious site in Sudan.

Explanatory Notes:

Site Number – identity code, a unique site descriptor number for each site.

Location (latitude, longitude) – GPS position, compass bearings, maps, charts etc.

Observers' names, date, time, tide, depth, visibility.

Distance to nearest town – approximately, in kilometres.

Visibility – note whether the data is from a horizontal underwater measurement (e.g. off transect tape) or a vertical Secchi disc from the survey vessel; where practicable, always employ the same method.

Human litter – rubbish, fishing gear above and/or below water.

Type(s) of survey method used – Reef Check, Lifeform, Video, Biodiversity.

Reef type – fringing, patch, barrier, atoll.

Reef development – major (extensive reef flat > 50 m wide), moderate (reef flat < 50 m wide), incipient reef (some recent reef accretion but no reef flat), coral community (coral cover > 10% developed directly on non-reef rock, sand or fossil reef).

Other substrata – as appropriate.

Exposure to waves – sheltered, semi-sheltered, semi-exposed, exposed.

Slope angle – (average reef slope angle, nearest 10 degrees to horizontal).

Presence of crown-of-thorns starfish, *Drupella* snails, total or partial coral bleaching.

Notes – anecdotal information, local knowledge about the site, other observations and remarks.

3.3.2 Benthic Cover

A tiered set of three standard quantitative methods for assessing benthic cover is recommended:

- Reef Check line transects
- Lifeform line transects
- Video belt transects

This set of methods provides a range of options in terms of logistic capacity and expertise, and the amount and detail of data collected. With increasing expertise, it is recommended that national teams progress from the simplest Reef Check method to the more complex and data-rich Lifeform and Video belt methods.

Positioning and marking of transects

Transects should initially be positioned haphazardly or randomly within the chosen survey habitat, rather than in the best or worst areas, and should remain within relatively homogeneous biotopes or community types as far as is practicable. Subsequent to the initial selection, transects may be fixed permanently using steel pegs hammered or cemented into the reef substrate. In an initial survey, it is not mandatory to mark the precise locations of transects with steel stakes and it is at the discretion of national teams whether to mark the precise location of transects.

Where transects are to be marked permanently, steel stakes should be placed as markers in each transect, hammered into the substrate every 5 m (for 20 m line transects) or 10 m (for 50 m video transects), with the middle stakes smaller than the start and end point stakes. A strong plastic code marker (ca. 8–10 cm long by 4–5 cm wide by 0.2–0.3 cm thick) should be attached securely to the first stake of each transect for identification. Transect number (1–5) can be indicated on the plastic marker tag by punching the respective number of holes (1–4 for Reef Check, 1–5 for Lifeform or Video) through the respective tag. Sub-surface marker buoys or flags are also appropriate for marking sites, but can have problems in areas of strong current and/or wave action, becoming tangled, lost or collected by fishermen.

It is particularly important to minimize any damage to the reef during the marking of transects, as indeed during all survey work, taking great care not to damage corals and other sessile benthos. This is best achieved by good buoyancy control during diving.

Irrespective of whether survey transects are marked permanently or not, maps should be drawn of important conspicuous features of the reefs for ease of site relocation (e.g. position of transects in relation to large massive corals).

Modifications of the field techniques

For ease of statistical comparisons, it is important that the level of replication remains consistent among sites. In circumstances where biotopes are small and with little depth profile (e.g. Socotra Islands and Gulf of Aden, Yemen), the standard protocol of positioning transects next to each other linearly along the reef slope may not be appropriate. In such circumstances, the method should be modified to ensure that all transects are kept within the same biotope with no loss of replication. This can be achieved by positioning transects adjacent to each other but not overlapping (i.e. approximately parallel), rather than aligned linearly along the reef. Sufficient distance should be maintained between adjacent transects (e.g. approx. 15 m) to ensure that transects do not overlap, particularly given that fish belt transects (5 m wide) may be centred along the same line transects. Further, and as noted above, where specific site characteristics do not allow transects to be positioned within the recommended depth ranges (2–6 m and 7–12 m), the survey team should select appropriate survey depths.

REEF CHECK POINT-INTERCEPT LINE TRANSECTS

Quantitative assessment of the percentage cover of 10 categories of sessile benthos is made using four 20 m line transects, laid parallel to the selected depth contours at two depths at each site. The depths surveyed are 7–12 m and 2–6 m below the chart datum of low water (low tide mark or reef crest where no chart datum is available). Some sites may not be deep enough to survey both depths.

Surveys are conducted by scuba using a 100 m long transect tape laid along the selected depth contour from a haphazardly or randomly selected starting point on the reef slope, with the first 20 m transect starting from the beginning of the tape. The second transect starts after an interval of 5 m from the end of the first transect (i.e. start at 25 m) and similarly for the third (start at 50 m) and fourth transects (start at 75 m). Deep transects are surveyed first, in accordance with safe diving practice.

The 10 categories of benthos (substrate) recorded in transects are listed in the field data sheets (see substrate codes in Table 3.3). On each transect, a point sampling method is employed where the substrate located under the transect tape at 50 cm intervals is recorded on a waterproof data sheet (Table 3.3 and Appendix 3.7.3).

Detailed descriptions and photographs of the field and analytical methods can be found at Reef Check (www.reefcheck.org) and in HODGSON (1999).

Equipment: Scuba equipment, data sheets and board, transect tape measures (3 x 100 m tapes, 3 x 20 m tapes), underwater carry-bag, and medical kit.

Data storage: Field data are recorded on waterproof data sheets and input to a spreadsheet (e.g. EXCEL or similar) for storage and preliminary analysis. Examples of the spreadsheets are provided in Appendices 3.7.4 and 3.7.7.

Where logistics permit, it is advantageous to enter data from the field data sheets directly into the spreadsheet on a portable computer in the field at the end of each day. This provides the opportunity to check for any obvious errors immediately. Subsequently, data may be linked into the Reef Check global database.

Advantages: This method provides a rapid means of acquiring quantitative estimates of percentage cover of the major structural components of coral reefs without requiring detailed taxonomic knowledge, and is thus an ideal first step in developing survey expertise where little capacity exists. The method requires little in logistic support other than the essential items listed above.

Disadvantages: The method provides no information on coral community structure and, because of the limited number of sampling points (40 points per 20 m transect), may be prone to large variances in heterogeneous habitats. This potential for imprecision can limit the statistical power of the method for detection of significant trends in cover.

Recommendations: This method will form the initial standard survey method for coral cover in the RSGA region, being replaced progressively by more complex

Site No.	SU-001a	**Reef name:**	Persga Bay		
Depth:	8-11 m	**Time:**		**Date:**	15 May 2001
Team Leader:				**Data recorded by:**	

Substrate Code

HC hard coral	**SC** soft coral	**DC** dead coral
FS fleshy seaweed	**SP** sponge	**RC** rock
RB rubble	**SD** sand	**SI** silt/clay
OT other		

TRANSECT 1				**TRANSECT 2**				**TRANSECT 3**				**TRANSECT 4**			
0 - 19.5 m				**25 - 44.5 m**				**50 - 69.5 m**				**75 - 94.5 m**			
0 m	HC	10.0 m	DC	25 m		35 m		50 m		60 m		75 m		85 m	
0.5	DC	10.5	OT	25.5		35.5		50.5		60.5		75.5		85.5	
1	SD	11.0	HC	26		36		51		61		76		86	
1.5	RC	11.5	HC	26.5		36.5		51.5		61.5		76.5		86.5	
2	HC	12.0	HC	27		37		52		62		77		87	
2.5	OT	12.5	RB	27.5		37.5		52.5		62.5		77.5		87.5	
3	RB	13.0	DC	28		38		53		63		78		88	
3.5	RB	13.5	DC	28.5		38.5		53.5		63.5		78.5		88.5	
4	HC	14.0	HC	29		39		54		64		79		89	
4.5	HC	14.5	HC	29.5		39.5		54.5		64.5		79.5		89.5	
5	HC	15.0	SD	30		40		55		65		80		90	
5.5	FS	15.5	SD	30.5		40.5		55.5		65.5		80.5		90.5	
6	FS	16.0	RC	31		41		56		66		81		91	
6.5	SC	16.5	FS	31.5		41.5		56.5		66.5		81.5		91.5	
7	SP	17.0	FS	32		42		57		67		82		92	
7.5	SD	17.5	SP	32.5		42.5		57.5		67.5		82.5		92.5	
8	SD	18.0	SP	33		43		58		68		83		93	
8.5	SD	18.5	HC	33.5		43.5		58.5		68.5		83.5		93.5	
9	SD	19.0	HC	34		44		59		69		84		94	
9.5	DC	19.5	HC	34.5		44.5		59.5		69.5		84.5		94.5	

Table 3.3 Example of a partially completed Reef Check point-intercept line transect field data sheet at a fictitious survey site in Sudan.

Explanatory Notes:
Some site description is completed in the top section of the data sheet. A unique site code number is used to link the transect data with the site description data sheet (see Table 3.2). Results of the point sampling of the four 20 m transects are recorded in the lower portion of the data sheet; for first segment (replicate transect), if the start point is 0 m, the last point is 19.5 m).

methods as expertise and logistic support develops. The survey design of national programmes will depend on capacity and logistics, but for ease of statistical comparison within the region, countries with low capacity should aim to survey fewer sites using the standard method (i.e. 4 x 20 m line transects at one or two depths per site), rather than changing the method. Training can be improved by videotaping transects for subsequent discussion, if logistics permit.

Lifeform line-intercept transects

This method provides quantitative estimates of cover of corals and other sessile benthic attributes using Lifeform line-intercept transects (Bradbury et al. 1986; DeVantier 1986; English et al. 1997). Sets of five 20 m long transects are surveyed using scuba at one or two depths (2–6 m and 7–12 m where appropriate) at the selected survey locations. The transects are laid along these depth contours from haphazardly or randomly chosen starting positions on the reef slopes, and may be marked permanently with steel pegs hammered firmly into the reef slopes at 5 m intervals.

This method is similar to Reef Check in that it employs line transects to estimate percentage cover of corals and other sessile benthic organisms quantitatively. However, it differs from Reef Check in that this is a line-

Lifeform	Group	Code
Acropora tabular	Scleractinia, *Acropora*	ACT
Acropora branching	Scleractinia, *Acropora*	ACB
Acropora encrusting	Scleractinia, *Acropora*	ACE
Acropora digitate	Scleractinia, *Acropora*	ACD
Acropora submassive	Scleractinia, *Acropora*	ACS
Coral massive	Scleractinia, non-*Acropora*	CM
Coral branching	Scleractinia, non-*Acropora*	CB
Coral submassive	Scleractinia, non-*Acropora*	CS
Coral foliose	Scleractinia, non-*Acropora*	CF
Coral encrusting	Scleractinia, non-*Acropora*	CE
Coral mushroom	Scleractinia, non-*Acropora*	CMR
Heliopora	Alcyonaria, blue coral	CHL
Millepora	Hydrozoa, fire coral	CME
Tubipora musica	Alcyonaria, organ pipe coral	CTU
Soft coral	Alcyonaria, gorgonians, sea whips etc.	SC
Dead coral	Recently dead corals with no visible algae	DC
Dead coral with algae	Dead standing corals with algae	DCA
Sponge	Porifera	SP
Zoanthid	e.g. *Palythoa, Protopalythoa, Zoanthus* spp.	ZO
Other living benthos	Anemones, ascidians etc.	OT
Mixed algal assemblage	Various algae	AA
Coralline Algae	Crustose coralline algae	CA
Turf Algae	Short turf algae	TA
Macro-Algae	Large fleshy algae	MA
Halimeda	Calcareous green algae	HA
Sand	Reefal origin	SD
Rubble	Dead broken coral etc.	RB
Silt	Terrestrial origin	SI
Rock	Rock not covered by other benthos	RCK
Water	Fissures deeper than 50 cm	WA
Other	Missing data	DDD

Table 3.4 Categories of sessile benthic lifeforms surveyed using the GCRMN Lifeform line-intercept transect protocol (after DeVantier 1986; English et al. 1997).

SITE No:	SU-001a	**Reef Name:**	Persga Reef	**Transect No.**	1			**Obs:**	
Lat:		**Depth:**	8 – 11 m	**Tide:**	High	**Time:**	1100 hrs	**Date:**	15 May 2001
Long:		**Visibility:**	15 m	**Reef type:**	Fringing	**Temp sea:**	30 C	**Temp air:**	33 C

Benthos	**Transition**	**Benthos**	**Transition**	**Benthos**	**Transition**	**Benthos**	**Transition**	**Benthos**	**Transition**
ACT	105	CF	2000						
SD	155								
ACB	278								
OT	344								
CM	389								
ACT	490								
SD	788								
RB	1004								
ACB	1466								
DCA	1781								
RB	1855								
CB	1866								
CS	1874								
DCA	1896								
OT	1932								
CMR	1938								
SD	1965								
RB	1977								

Table 3.5 Example of data entry for benthic cover on partially-completed Lifeform line-intercept transect data sheet, for a fictitious survey site in Sudan.

Notes:
General site information is completed in the top section of the data sheet. Results of the line-intercept sampling of each of five 20 m transects are recorded in the lower portion of the data sheet. The benthic code is recorded in the left-hand column (under Benthos) and the end-point of that benthic category (= start of the next category along the transect tape – Transition) is recorded (in cm.) in the adjacent right-hand column.

intercept method, rather than point-intercept. The observer swims slowly along each transect, recording the end point (transition) of each lifeform (one of the 31 'lifeform' categories, Table 3.4) on the standard data sheet (Table 3.5 and Appendix 3.7.5), rather than the benthic attribute located under points at 50 cm intervals along the transect (Reef Check). Thus the intercept of each sessile benthic organism with the transect tape is recorded (Tables 3.4 and 3.5), producing more detailed cover data and requiring a more detailed taxonomic knowledge of the benthos (31 categories instead of 10 as in Reef Check).

An example of data entry to the field data sheet is provided in Table 3.5. A detailed description of the method is provided in ENGLISH et al. (1997).

Equipment: scuba equipment, standard data sheets and board, transect tape measures (10 x 20 m tapes), underwater carry-bags, and medical kit.

Data storage: Field data are input to the ARMDES database provided free of charge by the Australian Institute of Marine Science (AIMS, www.aims.gov.au) for storage and preliminary analysis of percentage cover. The data entry programme also provides an error-checking function. Where logistics permit, it is advantageous to enter data from the field data sheets directly onto a portable computer in the field at the end of each day.

Advantages: This method requires little logistical support and thus is suitable for isolated locations. Survey observers can be trained to collect accurate data in a short time period (ca. 1 week training course). The method provides data with greater taxonomic resolution and usually higher levels of precision than does Reef Check. As observers' levels of taxonomic expertise increase, more detailed data can be collected, initially at family-genus level and ultimately at genus-species level.

Disadvantages: The method is more time consuming and requires a greater level of taxonomic expertise than Reef Check. For collection of demographic data, quadrat and belt transect methods are more appropriate. As with other methods, great care must be taken to ensure all observers are well trained and consistent in recording the standard 31 benthic categories (ENGLISH et al. 1997; DEVANTIER et al. 1999).

Recommendations: National and regional training courses may be initiated once capacities have developed sufficiently using Reef Check. Regular refresher training courses may be organized to ensure consistency in data collection within and among countries. As with Reef Check, training can be improved by videotaping transects for subsequent discussion, where logistics permit.

VIDEO BELT TRANSECTS

The field methods are similar to line transects in terms of the positioning of transects, as described above. Individual video transects are longer (50 m) than line transects (20 m), and a band of benthos is filmed (ca. 40 cm wide) rather than a line (DEVANTIER & DONE 1995; CHRISTIE et al. 1996; ENGLISH et al. 1997; OXLEY 1997). Series of five replicate transects are filmed at one or two depths per site, depending on the local reef characteristics and the discretion of the local survey team. The video operator swims at a constant speed (ca. 10–12 m per minute such that a 50 m transect takes 4–5 minutes to film) and height (ca. 25–30 cm) above the transect line. The camera is held perpendicular to the benthos. An underwater data sheet showing the site details, depth and transect number is recorded prior to filming each video belt transect (Table 3.6). General site characteristics are also filmed. A detailed description of the method is provided in CHRISTIE et al. (1996) and OXLEY (1997).

Equipment: Scuba equipment, standard data sheets and board, video camera (digital Hi8), underwater video camera housing and videotapes, ten 50 m transect tape measures.

Data storage: The field data are stored on videotapes, with digital archival using compact disc or other digital media. Quantitative data produced from analysis of the videotapes are stored in spreadsheets or a customized database available from AIMS at www.aims.gov.au.

Advantages: The method is very quick underwater, enabling large numbers of transects to be recorded in a short period (1 x 50 m transect requires ca. 4 to 5 minutes to film) in comparison with Lifeform line-intercept transects, which can take an experienced observer more than 30 minutes per transect. The method is cost-effective in terms of laboratory analysis. It also provides a permanent videorecord of the survey site, which is highly useful for showing the characteristics of sites to MPA managers and other decision makers. The results of analysis (percentage cover of corals and other sessile benthos) are compatible with results from line transects, enabling the method to be used as a follow-up to line transect surveys as expertise and logistic capacity allow. The video transect data are also compatible with more detailed forms of demographic analysis, by mapping of the individual corals present on the transects (Vogt 1996).

Disadvantages: Although cost-effective in the field and laboratory, the method is reliant on expensive equipment, requiring careful maintenance and on-going costs of videotape archival. The method also requires skilled personnel for laboratory analysis.

Recommendations: This method should form the third phase in the benthic survey of coral cover in the RSGA region, following Reef Check point-intercept and Lifeform line-intercept transects, being phased in as logistics and capacity allow.

3.3.3 Biodiversity

Corals

Scuba swim bio-inventory

A detailed inventory of corals is compiled during three replicate timed scuba-swim searches, each of 50–minutes duration, at one or two depths per site. Each of the three 50–minute timed swims is subdivided into five 10–minute subsections.

The observers swim slowly along the reef slope within the chosen depth range, recording each coral species seen per 10–minute segment onto the standard data sheet (Table 3.7 and Appendix 3.7.6). Species that cannot be readily identified underwater should be photographed and a sample collected for later identification in the laboratory, where permitted by MPA or other regulations (see below).

This method provides a comprehensive coral species list for each site. The method also provides a crude estimate of relative

Reef Name:	Persga Bay	SITE Code No:	SU-001a	Transect No.:	1	Obs:	
Lat:		Depth:	8 – 11m	Date:	15 May 2001	Temp. sea:	30 °C
Long:		Visibility:	15 m	Time:	1200 hrs	Tide:	High

Table 3.6 Example of partially completed field data sheet for recording information during filming of video transects at a fictitious survey site in Sudan. Table is repeated for transects 2 to 5 (see Appendix 3.7.8).

abundance of each species at each site, with the highest score for any species being 15 (recorded in every 10–minute swim from the three replicate 50–minute swim searches). With appropriate analysis this method can indicate the types of benthic communities present.

Coral taxa are identified underwater to the following levels, based on the taxonomic sources cited below:

Stony – hard corals – to species wherever possible (VERON & PICHON 1976, 1980, 1982; VERON, PICHON & WIJSMAN-BEST 1977; SCHEER & PILLAI 1983; VERON & WALLACE 1984; VERON 1986, 1993, 2000, 2002; HOEKSEMA 1989; SHEPPARD & SHEPPARD 1991; SHEPPARD 1997; WALLACE 1999), otherwise to genus with a description of the growth form.

SITE No: SU-001a **Reef Name:** Persga Bay			**Date:** 15 May 2001	**REEF**
Lat:	**Replicate:** 1	**Tide:**	**Time:** 1200 hrs	**Obs:**
Long:	**Visibility:** 15 m		**Temp sea:** 30 C	**T. air:**
Depth: 8 – 10 m			**Photo:**	
Field Notes:				

Taxa	**0 - 10 min**	**10 - 20 min**	**20 - 30**	**30 - 40**	**40 - 50**	**Taxa**	**0 - 10 min**	**10 - 20 min**	**20 - 30**	**30 - 40**	**40 - 50**	**Taxa**	**0 - 10 min**	**10 - 20 min**	**20 - 30**	**30 - 40**	**40 - 50**
Pdam						Ffung						Lpurp					
Pver						Fconc						Ltrans					
Shys						Fsimpl											
Smam						Fval						E forsk					
Spist						Herpol						E fruit					
Swels												Egem					
Mcirc																	
Mdan																	
Mmon						Gfasc						Tirreg					
Mstil						Easp						Tpel					
Mtub						M elep											
						Lcory											
Aaust						Lhemp											
Aclath																	
Aeuryst						Hexes						Mille					
A form						Hmicr											
Agem						Mscher											

Table 3.7 Example showing the top half of a coral bio-inventory data sheet, for a fictitious survey site in Sudan (see Appendix 3.7.6).

Notes:

Some general site information is completed in the top section of the data sheet, with a unique site code number to link the bio-inventory data to the site description data sheet (Table 3.2). The occurrence of each coral species in each 10 min. segment of the three 50 min. scuba swims is recorded in the lower portion of the data sheet. Common coral species in the RSGA region are listed as abbreviations in the left-hand columns. Empty spaces in the species column are available for the observer to record species not listed in the standard data sheet.

It is recommended that the series of coral field identification guides '*Corals of the World*' (VERON 2000) and the CD 'Coral ID' (www.aims.gov.au/coralid) be used as the standard taxonomic reference for stony corals in the RSGA region. Other useful field identification aids include HOEKSEMA (1989) for the family Fungiidae, SHEPPARD & SHEPPARD (1991), SHEPPARD (1997) for Indian Ocean corals and WALLACE (1999) for the staghorn genus *Acropora*.

Taxa that cannot be identified reliably to species level in the field should be photographed (colony and close-up), and a sample collected for later identification (where permitted) using national and/or regional reference collections and in consultation with taxonomic experts. Two comprehensive reference collections exist, one at NCWCD headquarters (Riyadh) for stony corals of the central-northern Red Sea and the other at the Socotra Biodiversity Project headquarters (Hadibo, Socotra) for stony corals of Socotra, Gulf of Aden and the Arabian Sea.

Soft corals, gorgonians, zoanthids, anemones and corallimorpharians – to genus or higher taxonomic level, family or order (ALLEN & STEEN 1994; COLIN & ARNESON 1995; GOSLINGER et al. 1996; REINECKE 1998). Reliable identification to species-level is presently not possible for many of these taxa in the field. A comprehensive field guide for the tropical Indo-west Pacific genera of soft corals and gorgonians has recently been prepared (FABRICIUS & ALDERSLADE 2000, and see www.aims.gov.au for details).

Equipment: Scuba equipment, standard data sheets and board, waterproof watch, underwater camera (optional), coral field guides.

Data storage: Data are stored in spreadsheets or databases. A typical spreadsheet for data storage is easily developed from the field data sheets provided in Appendices 3.7.6 and 3.7.9.

Advantages: Semi-quantitative bio-inventories provide a rapid means of assessing biodiversity in comparison with the more labour-intensive, quantitative quadrat or belt transect methods. Because of the often-high numbers of species with low relative abundance on coral reefs, quantitative census alone (e.g. quadrats, belt transects, line transects) tends to miss rare species. For this reason, quantitative assessments are best combined with semi-quantitative scuba-swim searches.

Disadvantages: Biodiversity surveys, both semi-quantitative and quantitative, require a high level of taxonomic expertise and access to reference materials.

Recommendations: Improved taxonomic capacity should be developed from a series of workshops focusing on key taxonomic groups. Standard reference collections should be assembled in each country and used as often as possible during training courses.

Collecting for Reference

Coral samples (specimens) collected for identification should be small (usually less than 10 cm on longest axis) and representative of the sampled coral colony. Samples should be carefully removed from the coral colony in situ, causing minimum damage, and leaving the remainder of the sampled colony intact. For solitary-polyp mushroom corals, the entire coral is collected. All sampling should be kept to the absolute minimum necessary for accurate identification. To achieve this end, surveyors should familiarize themselves with the different species using the taxonomic references cited. For the mushroom corals, careful inspection of the ornamentation and arrangement of septa on the oral (top) and costae on the aboral surfaces allows field identification of most species.

It is particularly important to take great care when sampling as most corals (and other sessile benthos) are fragile, easily injured and may become more susceptible to infection and disease. Great care is also required in handling and transporting of specimens to avoid breakage, both during the survey and on return to the laboratory. During transport, all specimens should be carefully wrapped in paper and packed securely in a strong, solid container, with the heaviest, most robust samples (e.g. massive corals) placed at the bottom, and progressively more delicate specimens (e.g. stout branching, fine branching, foliose corals) placed on top.

While in the field, all specimens should be labelled with collection information (specimen code no., site, date, depth, transect or replicate no., collector etc.) using a pencil on a waterproof plastic label tied securely with fishing line or other suitable material to the sample. Specimen codes may be the same as those used for each site description, with the addition of a unique specimen number (e.g. spm1, spm2, etc.).

At the base camp or laboratory, the living coral tissue is removed from the specimens by bleaching overnight with household bleach. Labels must be securely attached before bleaching. Specimens are then soaked and carefully washed with freshwater and dried. The dried specimens are examined using a hand-lens and/or binocular microscope, and identified, as far as possible, to genus and species level using the taxonomic references cited. A representative selection of the bleached, identified coral samples can then be stored as a permanent reference collection.

Other benthos

Reef Check

The abundance of selected benthic organisms is assessed in four belt transects 20 m long and 5 m wide (100 m^2) centred on the Reef Check line transects (2.5 m either side of the line) at each site. The organisms include: giant clams (*Tridacna* spp.), pencil urchins (*Heterocentrotus mammillatus*, *Eucidaris* spp.), long-spined urchins (*Diadema* spp.), sea cucumbers (*Holothuria scabra*, *H. fuscogilva*, *Stichopus chloronotus*), crown-of-thorns starfish (*Acanthaster planci*), giant triton (*Tritonia charonis*), flamingo tongue (*Cyphoma gibbosum*), banded coral shrimps (*Stenopus hispidus*) and lobsters (*Panulirus* spp.).

Broken coral (approximate area) and items of human litter (trash) are also recorded. Photographs of the above species are provided on the Reef Check website.

The survey observer swims slowly along each belt transect, searching systematically for the organisms listed above, and recording their occurrence on a standard data sheet which can be prepared to match the data sheet in Appendix 3.7.7.

Data storage: Data are stored on the standard Reef Check EXCEL spreadsheet (Appendix 3.7.7).

Advantages: In targeting a small number of easily identified species, the method is quick to learn and easily replicated. These quantitative surveys of selected taxa provide demographic data not obtainable using the semi-quantitative methods. A detailed description of the method is available on the Reef Check website.

***Disadvantages**:* There is no information on most non-coral groups, other than the small number of target species.

***Recommendations**:* Improved taxonomic capacity should be developed from a series of workshops focusing on key taxonomic groups.

Fish

Detailed guidelines for fish surveys are provided in a separate chapter of this publication. However, a brief introduction to the Reef Check method is given here.

Reef Check

Four replicate 100 m^2 (20 m long x 5 m wide) belt transects centred on the four 20 m line transects (2.5 m either side of the line) are surveyed in each depth range (7–12 or 2–6 m). Following placement of the transects, the fish observer should wait for up to 15 minutes to allow the fishes to resume their normal behaviour (CARPENTER et al. 1981). The observer then swims slowly down each transect recording fishes that are distributed within the borders of the transect on a standard data sheet (Appendix 3.7.7). The target fish species counted in each transect include: grouper (*Cephalopholis* and *Epinephelus* spp.) and coral trout (*Plectropomus* spp.) over 30 cm in total length (all species), barramundi cod (*Cromileptes altivelis*), sweetlips (family Haemulidae – *Plectorhynchus* spp.), humphead (Napoleon/Maori) wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometopon muricatum*) and butterfly fish (all species of family Chaetodontidae). Details of method and photographs of the fishes are provided at www.reefcheck.org.

3.4 DATA ANALYSIS

There are several key considerations relevant to the efficient storage, analysis and interpretation of the large amounts of data that will be produced, in relation to maintaining:

- Consistency of data types across the RSGA region
- Simplicity and reliability of data entry systems
- Reliability of backup and archival systems
- Utility, simplicity and efficiency of analytical tools
- Consistency of data presentation and reporting.

Consistency of data types should be maintained by the application of the standard methods described herein. For these methods, simple and reliable data entry and archival systems have been developed in MICROSOFT EXCEL (i.e. Reef Check and biodiversity data) and the ARMDES database (Lifeforms). These standard methods also have simple and efficient methods of analysis, data presentation and reporting. For biodiversity surveys, initial data entry is most simply executed in spreadsheets (e.g. EXCEL or equivalent) and exported to a custom-designed database (in ACCESS or equivalent) for long-term storage.

The simplest kinds of analysis are descriptive summary statistics, namely mean and variance (standard deviation, standard error), mode and median. These are available in standard form in most commercial spreadsheet and database programmes. A wide variety of more complex statistical tools is also commercially available for the analysis of survey data. These are broadly divisible into univariate and multivariate methods.

Univariate analyses are designed to examine differences or trends in one group of organisms (e.g. changes in coral cover among sites and/or through time, where 'repeated measures' type tests (e.g. GREEN 1993) may be appropriate if 'fixed' transects are marked permanently). These analyses tend to be used to test null hypotheses of the level of significance of changes or of impacts. Univariate analyses are divisible into parametric and non-parametric tests. For parametric tests, there are several statistical assumptions about the nature of the field data (e.g. normal distribution, homogeneity of variances) that need to be met prior to analysis. The fit of the data to the assumptions can be examined statistically (e.g. UNDERWOOD 1981). For field data that do not meet the assumptions, various data transformations (e.g. square-root transformation, $\log_{10} + 1$ transformation, arc-sine transformation etc.) are applied to better meet the assumptions, or non-parametric tests (e.g. Kruskal-Wallis ANOVA type tests) may be used. For the methods described here, univariate analyses are most useful in examining differences in benthic percentage cover (Reef Check point-intercept transects, Lifeform line-intercept transects, Video belt transects) and invertebrate and fish abundances (Reef Check belt transects).

By contrast, multivariate analyses examine relationships among multiple groups of species (e.g. defining community types) or of species with multiple environmental variables (BROWN 1986; HARGER 1986; JONGMAN et al. 1995). These analyses tend to be used in hypothesis generation, rather than hypothesis testing. For the methods described here, multivariate analyses are most useful in defining coral community types from the biodiversity data and in exploring relationships among coral communities, coral cover and environmental variables (see later).

The application of statistical analysis in ecology is a complex and rapidly expanding field (e.g. GREEN 1979, 1993; HURLBERT 1984; ANDREW & MAPSTONE 1987; JAMES & MCCULLOCH 1990; MORRISEY 1993; SHEPPARD 1999b). The interested reader is further referred to the references below: univariate – UNDERWOOD (1981, 1993), SNEDECOR & COCHRAN (1989), WINER et al. (1991), SOKAL & ROHLF (1995); multivariate – CLIFFORD & STEPHENSON (1975), GRAY et al. (1992), CLARKE (1993), JONGMAN et al. (1995), DEVANTIER et al. (1998), DE'ATH & FABRICIUS (2000), DE'ATH (2002).

3.4.1 Site Description

Descriptive summary statistics from the site description data can be extracted using standard analysis packages in most spreadsheet programmes. Useful spreadsheet functions include *Count* and *Sum*, and the summary statistics *mean* and *standard deviation* or *standard error, mode* and *median*. In EXCEL, these are found in the 'drop-down' menus: *Tools – Data Analysis – Descriptive Statistics*.

3.4.2 Benthic Cover

Reef Check point intercept line transects

To calculate the percentage cover of each of the 10 sessile benthic categories in each 20 m transect manually, the number of occurrences of each category is summed, divided by the total possible number of occurrences (40 points per 20 m transect) and multiplied by 100 to produce a percentage. Thus, for example, if the sum of occurrences of hard corals (HC) is 20 points in a transect, then its percentage cover in that transect is: 20/40 x 100 = 50%.

This procedure is followed for all of the benthic categories present in each transect, with the sum of all individual percentage cover calculations equalling 100%.

To determine the mean or average percentage cover of each benthic category at one depth (four transects), the percentage cover values for the four transects are added together and divided by four. Thus for example, if the four percentage cover values for hard corals in each of the four transects are: Transect 1: 50%; Transect 2: 30%; Transect 3: 60%; Transect 4: 40%, then the mean percentage cover is (50 + 30 + 60 + 40) divided by 4 = 45%.

Calculations of the mean cover, and the level of variation around the mean (standard deviation or standard error), are most easily performed using standard functions in spreadsheets. In the case of Reef Check, the field data entry spreadsheet in EXCEL provides calculations of mean percentage cover and variance (standard deviation) at each depth and site (Appendix 3.7.4). Results are usually displayed using bar graphs (see Data Presentation).

Univariate statistical analysis (usually analysis of variance – ANOVA) is used to examine the significance of differences in percentage cover between depths at a single site, or among sites. The ANOVA model will vary depending on the particular sampling design. Suitable software for data analysis is available in most commercial statistical packages. HODGSON (1999) presents regional and global-scale Reef Check analyses, including multivariate clustering dendrograms (Bray-Curtis similarity index) and ecological indices of coral reef health and impact perception.

The total amount (cover) of coral at different reefs can vary widely under natural conditions in relation to differences in environment and geomorphology. A useful interpretation of the results is the determination of the *ratios* of live hard coral to dead coral and total live coral (hard plus soft) to dead coral, at each depth and site (HODGSON 1999; DEVANTIER et al. 2000b), rather than comparisons of live coral cover among sites *per se*.

Lifeform line-intercept transects

To calculate the percentage cover of each of the 31 sessile benthic categories in each 20 m transect manually, the total length of the line-intercept of each category is determined, then divided by the total length of the transect (20 m) and multiplied by 100 to produce a percentage. Thus, as a simple example, if the intercepts for branching *Acropora* (ACB) for Transect 1 (Table 3.8) are:

Benthos	Transition	Intercept length (cm)
ACB	50	50
CB	100	
ACB	750	650
SD	1500	
ACB	1700	200
DCA	1850	
ACB	1950	100
SD	2000	

Table 3.8 Example of results of a lifeform line-intercept transect, showing benthic categories, intercepts on the transect (Transition) and the calculated length of each lifeform (Intercept length); benthos symbols from Table 3.4.

then total intercept length for ACB is the sum of the individual intercept lengths: 50 + 650 + 200 + 100 = 1000 cm. Percentage cover for ACB on this transect is: 1000/2000 (total transect length in cm) x 100 = 50%. This procedure is followed for all of the benthic categories present in each transect, with the sum of all individual percentage cover calculations equalling 100%.

As with Reef Check, to determine the mean or average percentage cover of a benthic category at one depth (five transects), the percentage cover values for that benthic category in the five transects are summed and divided by the number of transects (5).

The ARMDES database provided by AIMS (www.aims.gov.au) calculates cover and abundance (number of intercepts) of each of the benthic lifeforms recorded per transect, depth and site. These results are usually grouped into larger summary categories, such as:

- Acropora = ACB + ACT + ACE + ACS + ACD
- Other hard corals = CB + CS + CMR + CM + CE + CF + CME + CHL + CTU
- Hard corals = Acropora + other hard corals
- All live corals = hard corals + soft corals (SC)
- Dead corals = DC + DCA
- Algae = AA + CA + TA + MA + HA (Table 3.4).

These summary results are expressed as bar graphs of percentage cover (see Data Presentation). Statistical analysis of differences among sites is usually conducted with univariate ANOVA type statistics. The ANOVA model will vary depending on the particular sampling design. Suitable analysis software is available on most commercial statistical packages.

As with Reef Check, a useful interpretation of the results is the determination of the *ratios* of live hard coral to dead coral and total live coral to dead coral at each depth and site, rather than comparisons of live coral cover among sites *per se*.

Video belt transects

Analysis of a video transect is conducted initially by point-sampling the videotape on a television monitor connected to a video editor. Using the video editor, the tape is stopped at regular intervals (usually 70 stops per 50 m transect). The identities of the benthos (usually to genus level for hard and soft corals) located under five fixed points marked on the television monitor are recorded into a spreadsheet or database for the analysis of percentage cover (CHRISTIE & MAPSTONE 1994; CHRISTIE et al. 1996; OXLEY 1997). The five points are marked on the TV screen using a black permanent marker pen. The points are arranged in a face-centred pattern with two points towards the top of the screen, one point in the centre of the screen and two points towards the bottom of the screen.

More detailed demographic data may be obtained from the video record by mapping the benthos (VOGT 1996; VOGT et al. 1997), rather than by point-sampling. The level of taxonomic resolution is dependent on the expertise of the observer and can be standardised by using the same benthic categories as those of the Reef Check or Lifeform transect methods (i.e. the 10 Reef Check categories, or the 31 Lifeform categories). For expert observers, video transects can be analysed at genus and species levels. Once the results are input to a spreadsheet or database, typical statistical analyses include ANOVA, although useful interpretations can be gained from multivariate approaches (see section on Data Presentation).

As with Reef Check and Lifeform methods, a useful interpretation of the results is the determination of the ratios of live coral to dead coral at each depth and site, rather than comparisons of live coral cover among sites *per se*.

3.4.3 Biodiversity

The simplest form of analysis is to produce summary descriptive statistics of species richness at each site, using standard analysis packages provided in most spreadsheet programmes. Useful spreadsheet functions include *Count* and *Sum*, and the summary statistics *mean* and *standard deviation* or *standard error, mode* and *median*. In EXCEL for example, these are found in the 'drop-down' menus: *Tools – Data Analysis – Descriptive Statistics*.

The statistical significance of differences in species richness among sites can be assessed with ANOVA or similar univariate statistics, using richness values (counts) from each of the three replicate 50–minute 'swim-searches' at each site as the base data values.

Various forms of multivariate analysis have been used with coral biodiversity data (e.g. DONE 1982; SHEPPARD & SHEPPARD 1991; DEVANTIER et al. 1998, 2000b), principally to define coral community types and the relations among communities and various environmental variables. Coral community types can be assessed with various forms of hierarchical cluster analysis, using a data matrix composed of species presence – absence or relative abundance (1–15) data from all sites. Initially, such analyses may best be conducted on the pooled regional data.

Additionally, various ecological indices have been used to:

- Determine which are the key indicator species in different community types (e.g. DUFRENE & LEGENDRE 1997; DEVANTIER et al. 2000b)
- Compare sites in terms of the evenness or dominance of their community structures (e.g. Shannon-Weaver H')
- Determine which sites are likely to be important for replenishment and the conservation of rare species, important in MPA planning (DEVANTIER et al. 1998, 2000a,b)

The coral replenishment index (*CI*, adapted from DEVANTIER et al. 1998) rates sites based on a combination of their total coral cover and individual species abundance scores. Using the present set of methods, the index can be derived from combining the results of the coral cover transect and the coral biodiversity surveys for the same site:

$$CI = \sum A_i H_i / 100$$

where A_i = abundance of the i^{th} hard and soft coral taxon at a given depth or site (1–15, from the bio-inventory surveys) and H_i = combined percentage cover of hard and soft corals at the depth or site (from the benthic cover surveys). This index gives highest scores to sites that have high species richness, abundance and cover of corals.

The Rarity Index (*RI*, adapted from DEVANTIER et al. 1998) is derived solely from the biodiversity data. This index rates sites in terms of their species complement of rare versus common coral species:

$$RI = \sum A_i / P_i$$

where A_i = abundance rank for the i^{th} hard coral taxon at a given site (1–15, from the bio-inventory surveys) and P_i = the proportion of all sites in which the taxon was present. This index gives highest values to sites that are least representative or most unusual faunistically (i.e. with high abundance of taxa which are rare in the data set).

These indices can be calculated in spreadsheets, databases or statistical packages.

A skilled database technician and bio-statistician should establish national and regional databases. This proves valuable in maintaining:

- Consistency of data types across the region
- Simplicity and reliability of data entry systems
- Reliability of backup and archival systems
- Utility, simplicity and efficiency of analytical tools
- Consistency of data presentation and reporting.

3.5 DATA PRESENTATION

Reporting of survey results should be standardized as much as is practicable among countries within the region. Examples of various reporting formats are provided by OLIVER et al. (1995), SWEATMAN et al. (1998), Reef Check and GCRMN (WILKINSON 2000).

3.5.1 Site Description

Site description data should be placed in the appendices of reports.

Site locations can be marked on country maps. Other site description data should be placed in a standard table, initially in the data entry spreadsheet, which may be similar to the field data sheets (see Appendices), and ultimately exported into a word processing or publishing programme for presentation.

3.5.2 Benthic Cover

The three recommended methods for surveying benthic cover (Reef Check line transects, Lifeform line-intercept transects and Video belt transects) have a standard graphical form of presentation, namely bar graphs of mean percentage cover and variance of the important benthic attributes (e.g. hard corals, soft corals, dead corals, algae etc.). Bar graphs are easily produced in all spreadsheet and database programmes. For example, in EXCEL a variety of different graph types, including bar charts, is available from the *Chart Wizard* by following the ‘drop-down’ menu functions.

Reef Check line transects

Preliminary analyses of mean cover and standard deviation are conducted in the standard Reef Check EXCEL spreadsheet. A typical graphical presentation of mean percentage cover and variance of hard corals, dead corals and soft corals derived from Reef Check line transect data is given in Figure 3.2.

Lifeform line-intercept transects

Graphical representations of percentage cover results are available within the ARMDES database. These are typically represented as bar graphs of the mean cover and variance (standard deviation or standard error) of the major Lifeform categories at a single site or among different sites.

Video belt transects

Video transects produce similar results to Lifeform line transects, that is quantitative estimates of percentage cover of various benthic attributes, usually expressed in bar graphs as mean cover and variance (standard deviation or standard error of the mean, Figure 3.3). Multivariate analyses (e.g. various forms of hierarchical clustering, multi-dimensional scaling or principal

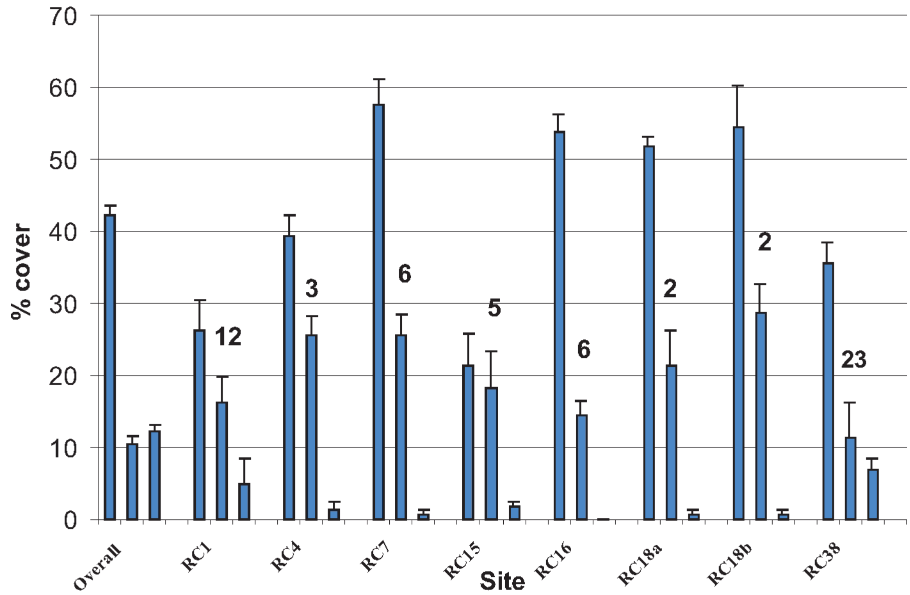

Figure 3.2 Example of results of Reef Check line-transect surveys for percent cover (error bars – 1 standard error) of hard corals (first bar), dead corals (mid bar) and soft corals (third bar) at eight sites in the Saudi Arabian Red Sea 1998. The numbers above each site show counts of crown-of-thorns starfish (from DeVantier et al. 2000b).

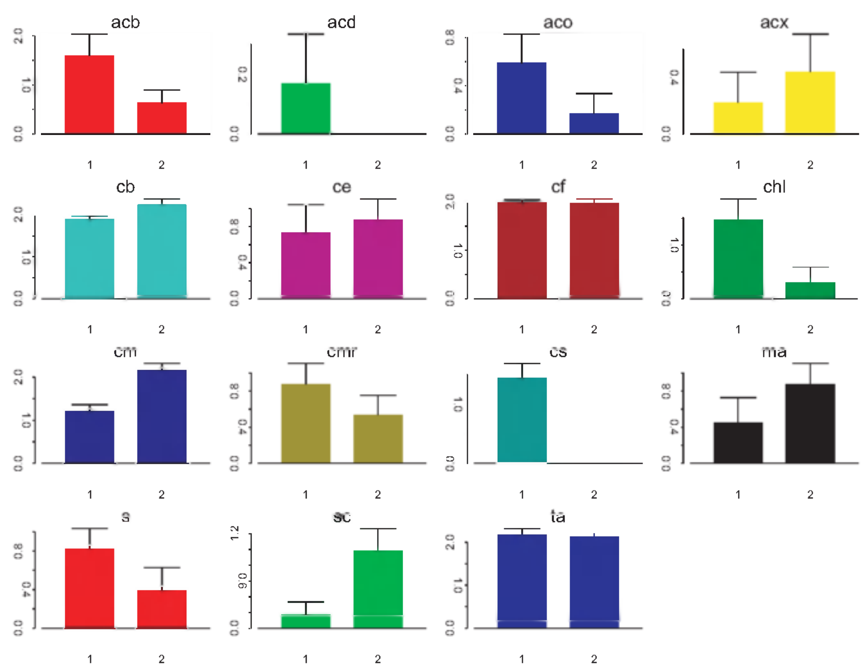

Figure 3.3 Example of bar graphs illustrating differences in various categories of benthic cover assessed using sets of five 50 m video belt transects at two sites (1 and 2), with categories: acb – *Acropora* branching, acd – *Acropora* digitate, aco – *Acropora* corymbose, acx – *Acropora* bottlebrush, cb – coral branching, ce – coral encrusting, cf – coral foliose, chl – coral *Heliopora*, cm – coral massive, cmr – coral mushroom, cs – coral submassive, ma – macroalgae, s – sand, sc – soft coral, ta – turf algae.

Notes: Typical graphical representation of differences in percentage cover between two monitoring sites. These differences were significant (1 way ANOVA, alpha 0.05) for *Heliopora*, coral massive, coral submassive, coral branching and soft corals.

components analysis) are also useful means of presenting and interpreting the results (e.g. Figure 3.4).

3.5.3 Biodiversity

Typical presentation of biodiversity results can be as simple as a species – site data matrix table, usually presented as an appendix to the report. More sophisticated presentations include graphical representations of coral community types derived from cluster analysis. These can include dendrograms illustrating the level of similarity among sites based on their species composition (presence – absence or relative abundance), generated using cluster analysis with various amalgamation schedules and distance measures. As noted above, there is a multitude of different statistical approaches to the analysis of biodiversity data (see e.g. JONGMAN et al. 1995 and Figure 3.5).

It is also useful to combine the analysis of different types of data (site description, benthic cover and biodiversity), exploring relationships among coral community types, benthic cover and environmental variables (e.g. Figure 3.6).

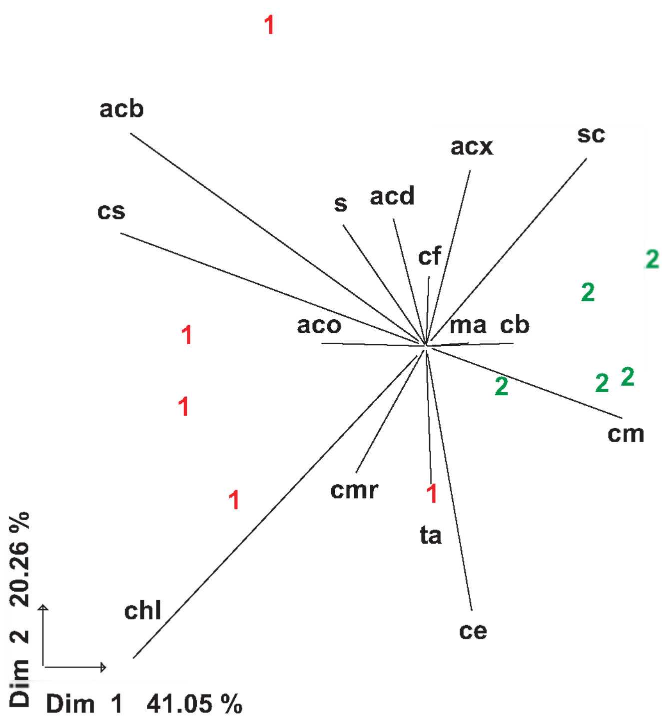

Figure 3.4 Example of principal components analysis biplot of differences in percentage cover of various lifeform categories in sets of five 50 m video belt transects at two sites (1 and 2). Individual transects are represented by 1 (Site 1) or 2 (Site 2). acb – *Acropora* branching, aco – *Acropora* corymbose, acd – *Acropora* digitate, acx – *Acropora* bottlebrush, cf – coral foliose, cs – coral submassive, cb – coral branching, cm – coral massive, cmr – coral mushroom, ce – coral encrusting, chl – coral *Heliopora*, ma – macroalgae, ta – turf algae. Principal component dimensions 1 and 2 account for 61% of the total variance. The vectors (lines) point in the direction of the highest cover for each of the lifeform categories.

Notes: The biplot is a way of graphically illustrating the relationship among transects in terms of their cover of the different lifeforms, and clearly indicates differences between the two sites. This analysis and graphical representation is a useful adjunct to the more commonly applied ANOVA and bar graphs approach.

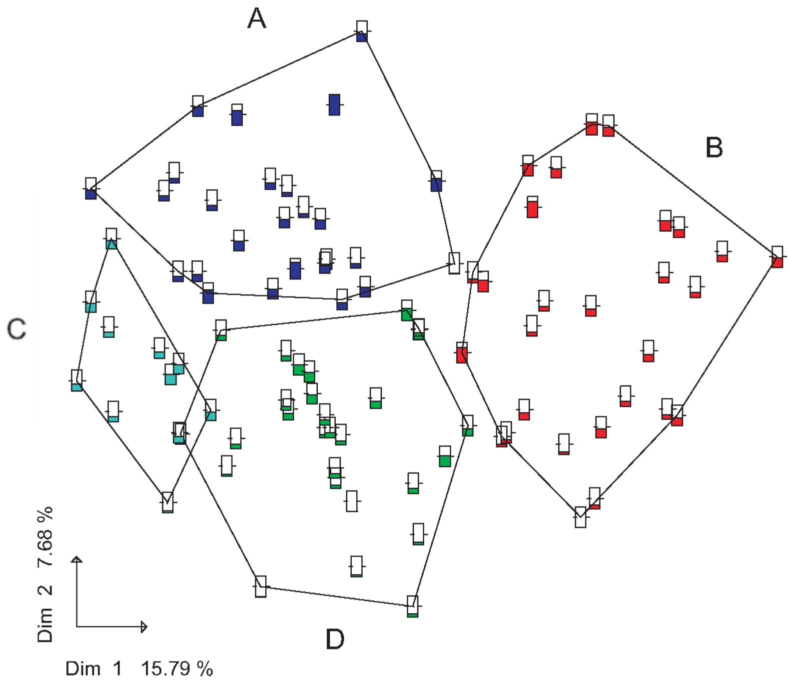

Figure 3.5 Example of multivariate analysis (hierarchical clustering using Euclidian metric, complete linkage) showing relationship among sites through species-abundance of four coral community site groups. Convex hulls delimit four community types A – D. Dimensions 1 and 2 account for ~ 24% of the observed variance. The amount of fill in the bars indicates score of each site on a Rarity Index indicating sites of high conservation value (data from DeVantier et al. 2000b).

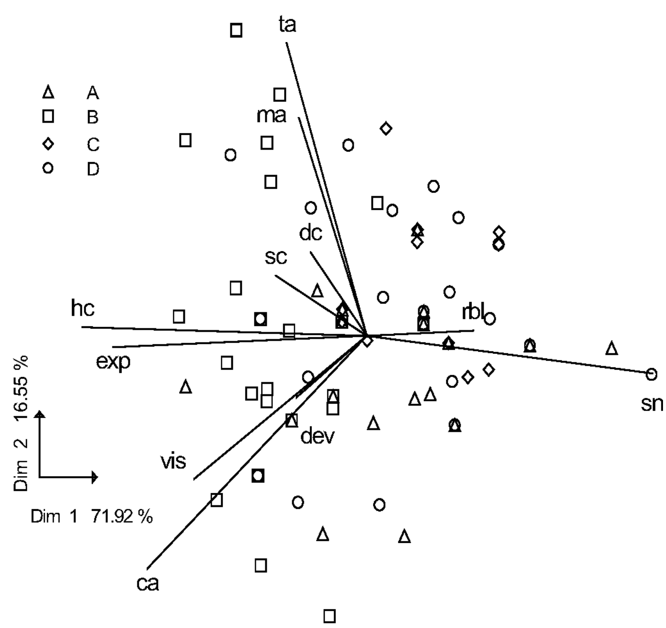

Figure 3.6 Example of multivariate analysis (principal components biplot) of relations among cover, environmental site descriptor variables and coral community types. Dimensions 1 and 2 account for ~ 90% of the observed variance. The vectors point in the direction of the highest scores for the indicated variables, where hc – stony coral, dc – dead coral, sc – soft coral, ta – turf algae, ca – coralline algae, ma – macroalgae, sn – sand, rbl – rubble, exp – exposure, dev – reef development, vis – water clarity. The symbols represent sites in each of four coral community type groups A – D (data from DeVantier et al. 2000b).

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Useful Web Sites

Remote Sensing – Environment and Ecosystem Properties

NOAA/NESDIS Hotspot anomalies, NOAA home page: www.noaa.gov

SST Hotspots: coralreefwatch.noaa.gov/satellite/

Seawifs: seawifs.gsfc.nasa.gov/seawifs.html

Survey (& Monitoring)

Reef Check: www.reefcheck.org

Lifeform line transects

Australian Institute of Marine Science site (AIMS) and ARMDES database: www.aims.gov.au

Video belt transects

Australian Institute of Marine Science: www.aims.gov.au

Rapid Ecological Assessment

Manta-tow: AIMS site and ARMDES database: www.aims.gov.au

Global Coral Reef Monitoring Network (GCRMN): www.gcrmn.org

General

WorldFish Center ReefBase: www.reefbase.org

Appendix 3.7.1 Example of a field data sheet for a sub-tidal site.

SITE No:	**Reef Name:**	**Weather:**	**Date:**	**Obs:**
Lat:	**Depth:**	**Tide:**	**Distance to nearest town:**	
Long:	**Visibility:**	**Time:** **Human litter:**		
Survey methods:	**Reef Check:**	**Lifeform:**	**Video:**	**Biodiversity:**

Map (show N point and scale)	**Profile (show vertical and horizontal distance)**

Reef type				**Reef development**				**Other substrata**			**Exposure**			
Fring.	**Patch**	**Barrier**	**Atoll**	**Major**	**Moder-ate**	**Incip-ient**	**Coral comm.**				**Shelt-ered**	**Semi-shelt.**	**Semi-expos.**	**Expo-sed**
Total Bleaching			**Partial Bleaching**			**Slope angle**	**COT Stars**	***Drup-ella***						

Notes:

See Table 3.2 for explanatory notes.

Appendix 3.7.2 Example of Reef Check site data sheet (source: www.reefcheck.org/).

Site name:

BASIC INFORMATION

Country: ____________ State/Province: ____________ City/town: ____________

Date: ____________ Time: Start of survey: ____________ End of survey: ____________

Latitude (deg. min. sec): ____________ Longitude (deg. min. sec): ____________

From chart or by GPS? (If GPS, indicate units): Chart____ GPS____ GPS units: ____________

Orientation of transect: N-S____ E-W____ NE-SW____ SE-NW____

Temperature (in degrees C): air: ____C surface: ____C at 3m: ____C at 10m: ____ C

Distance from shore (m): ____________ from nearest river (km): ____________

River mouth width: <10 m ____ 11-50 m ____ 51-100 m ____ 101-500 m ____

Distance to nearest population center (km): ____________ Population size (x1000): ____________

Weather: sunny ____ cloudy ____ raining ____

Visibility (m) : ____________

Why is this site selected: ____________ Is this best reef in the area? Yes: ____ No : ____

IMPACTS:

Is this site: Always sheltered: ____ Sometimes: ____ Exposed: ____

Major coral damaging storms Yes: ____ No ____ If yes, When was last storm: ____

Overall anthropogenic impact	None: ____	Low: ____	Med: ____	High: ____
Is siltation a problem	Never: ____	Occasionally: ____	Often: ____	Always: ____
Blast fishing	None: ____	Low: ____	Med: ____	High: ____
Poison fishing	None: ____	Low: ____	Med: ____	High: ____
Aquarium fishing	None: ____	Low: ____	Med: ____	High: ____
Harvest inverts for food	None: ____	Low: ____	Med: ____	High: ____
Harvest inverts for curio sales	None: ____	Low: ____	Med: ____	High: ____
Tourist diving/snorkeling:	None: ____	Low: ____	Med: ____	High: ____
Sewage pollution (outfall or boat)	None: ____	Low: ____	Med: ____	High: ____
Industrial pollution	None: ____	Low: ____	Med: ____	High: ____
Commercial fishing (fish caught to sell for food)	None: ____	Low: ____	Med: ____	High: ____
Live food fish trade	None: ____	Low: ____	Med: ____	High: ____
Artisinal/recreational (personal consumption)	None: ____	Low: ____	Med: ____	High: ____
How many yachts are typically present within 1km of this site	None: ____	Few (1-2): ____	Med (3-5): ____	Many (>5): ____

Other impacts:

PROTECTION:

Any protection (legal or other) at this site? Yes: ____ No: ____ If yes, answer questions below

Is protection enforced Yes: ____ No: ____

What is the level of poaching in protected area? None: ____ Low: ____ Med: ____ High ____

Check which activities below are banned:

- Spearfishing ____________
- Commercial fishing ____________
- Recreational fishing ____________
- Invertebrate or shell collecting ____________
- Anchoring ____________
- Diving ____________
- Other (please specify) ____________

Other comments ____________

TEAM INFORMATION

Submitted by ____________

Regional Coordinator: ____________

Team Leader: ____________

Team Scientist: ____________

Team Members: ____________

Appendix 3.7.3 Example of Reef Check point intercept line transect field data sheet, modified for RSGA region.

Site No.	**Reef name:**		
Depth:	**Time:**	**Date:**	
Team Leader:		**Data recorded by:**	
Substrate Code			
HC hard coral		**SC** soft coral	**DC** dead coral
FS fleshy seaweed		**SP** sponge	**RC** rock
RB rubble		**SD** sand	**SI** silt/clay
OT other			

(For first segment, if start point is 0 m, last point is 19.5 m)

TRANSECT 1				**TRANSECT 2**				**TRANSECT 3**				**TRANSECT 4**			
0 - 19.5 m				**25 - 44.5 m**				**50 - 69.5 m**				**75 - 94.5 m**			
0 m		10.0 m		25 m		35 m		50 m		60 m		75 m		85 m	
0.5		10.5		25.5		35.5		50.5		60.5		75.5		85.5	
1		11.0		26		36		51		61		76		86	
1.5		11.5		26.5		36.5		51.5		61.5		76.5		86.5	
2		12.0		27		37		52		62		77		87	
2.5		12.5		27.5		37.5		52.5		62.5		77.5		87.5	
3		13.0		28		38		53		63		78		88	
3.5		13.5		28.5		38.5		53.5		63.5		78.5		88.5	
4		14.0		29		39		54		64		79		89	
4.5		14.5		29.5		39.5		54.5		64.5		79.5		89.5	
5		15.0		30		40		55		65		80		90	
5.5		15.5		30.5		40.5		55.5		65.5		80.5		90.5	
6		16.0		31		41		56		66		81		91	
6.5		16.5		31.5		41.5		56.5		66.5		81.5		91.5	
7		17.0		32		42		57		67		82		92	
7.5		17.5		32.5		42.5		57.5		67.5		82.5		92.5	
8		18.0		33		43		58		68		83		93	
8.5		18.5		33.5		43.5		58.5		68.5		83.5		93.5	
9		19.0		34		44		59		69		84		94	
9.5		19.5		34.5		44.5		59.5		69.5		84.5		94.5	

Notes:

This is a modified example of the spreadsheet available at the Reef Check website for data entry. It can also be used for field data recording.

The numbers in the left columns refer to the metre number on the 100 m tape where the benthic category (listed in top portion of data sheet) that occurs under each point-intercept is recorded.

The standard Reef Check form lists the intercept points from 1 to 40 for the first transect (segment), 41–80 for transect 2, and so forth.

Appendix 3.7.4 Example of Reef Check point-intercept line transect analysis spreadsheet (EXCEL).

DO NOT TYPE DATA BELOW THIS LINE

Total S1	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0
#	0

Total S2	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0
#	0

Total S3	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0
#	0

Total S4	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0
#	0

Grand total	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0

Mean	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0

SD	
HC	0
SC	0
DC	0
FS	0
SP	0
RC	0
RB	0
SD	0
SI	0
OT	0

Notes:

This is an example of the spreadsheet available at the Reef Check website site for data entry and calculation of summary statistics.

S refers to Segment, equivalent to Transect in Table 3.3.

Total S1 EXCEL calculation for row HC: COUNTIF(B37:D37:F37:H37)

Mean (average) calculated from =AVERAGE(B37:D37:F37:H37)

SD calculated from =STDEV(B37:D37:F37:H37)

Appendix 3.7.5 Example of Lifeform line-intercept transect field data sheet.

<table>
<tr><td>SITE No:</td><td>Reef Name:</td><td colspan="2">Transect No.</td><td colspan="2">Obs:</td></tr>
<tr><td rowspan="2">Lat:

Long:</td><td>Depth:</td><td>Tide:</td><td>Time:</td><td colspan="2">Date:</td></tr>
<tr><td>Visibility:</td><td>Reef type:</td><td>Temp sea:</td><td>Temp air:</td><td></td></tr>
</table>

Benthos	**Transition**	**Benthos**	**Transition**	**Benthos**	**Transition**	**Benthos**	**Transition**	**Benthos**	**Transition**

Notes:

Benthos – the Benthos code intercepted by the transect tape (e.g. ACB for *Acropora* branching, see text).

Transition – the transition point between two different lifeforms (e.g. between ACB and the next lifeform intercepted by the transect tape).

Appendix 3.7.6 Example of coral biodiversity field data sheet.

SITE No:	**Reef Name:**		**Date:**		**REEF**
Lat:	**Replicate:**	**Tide:**	**Time:**		**Obs:**
Long:	**Visibility:**		**Temp sea:**	**T. air:**	
Depth:			**Photo:**		
Field Notes:					

Taxa	**0 - 10 min**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**Taxa**	**0 - 10 min**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**Taxa**	**0 - 10 min**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**
Pdam						Ffung						Lpurp					
Pver						Fconc						Ltrans					
Shys						Fsimpl											
Smam						Fval						E forsk					
Spist						Herpol						E fruit					
Swels												Egem					
Mcirc																	
Mdan																	
Mmon						Gfasc						Tirreg					
Mstil						Easp						Tpel					
Mtub						M elep											
						Lcory											
Aaust						Lhemp											
Aclath																	
Aeuryst						Hexes						Mille					
A form						Hmicr											
Agem						Mscher											
Ahemp												Tmus					
Ahum												Sarco					
Ahya						Ffav						Sinul					
Aphar						Flax						Sin tree					
Asec						Fmarit						Lithophyt					
Avalid						Fpal						Dendro					
Avar						Fspec						Paraeryth					
						Fstel						Xenia					
A myr						Bamic											
Agrac						Fabd											
						Fchin						Sponge					
Pcolum						Fflex											
Pmass						Fpent											
Pnod						Fperesi						Ascidian					
Prus																	
												Tridicna squa					
Gdjib												Diadema					
Gsom						Gedw											
						Gpect											
Alspong						Greti						Sargassum					
												Padina					
Ssav						Pdae						Turbinaria					
Pcont						Plam						Halimeda					
Pexp												Caulerpa					
Cmoneli						Lphry						ECA					
						Mcurta											
Pcact						P versip											
Pdec																	
Pmald												H. ovilis					
Pvar						Cchal						H. stipulacea					
Lfol						C micr						Thalasia					
Lmycet						Cser						Thalassoden					

Appendix 3.7.7 Example of a Reef Check data form for fish and invertebrates.

Site Name:			
Depth:		Team Leader:	
Date:		Time:	

Red Sea Belt Transect : Fish

Data recorded by:							
	0-20m	**25-45m**	**50-70m**	**75-95m**	**Total**	**Mean**	**SD**
Butterflyfish							
Sweetlips (*Haemulidae*)							
Snapper (*Lutjanidae*)							
Broomtail wrasse (*Cheilinus lunulatus*)							
Grouper >30cm (Give sizes in comments)							
Bumphead parrotfish (*Bolbometopon muricatum*)							
Humphead wrasse (*Cheilinus undulatus*)							
Any parrotfish (>20cm)							
Moray eel							

Red Sea Belt Transect : Invertebrates

Data recorded by:							
	0-20m	**25-45m**	**50-70m**	**75-95m**	**Total**	**Mean**	**SD**
Banded coral shrimp (*Stenopus hispidus*)							
Diadema urchins							
Pencil urchin (*Heterocentrotus mammillatus*)							
Sea cucumber (edible only)							
Crown-of-thorns star (*Acanthaster planci*)							
Giant clam (*Tridacna*)							
Triton shell (*Charonia tritonis*)							
Lobster							

For each segment, rate the following as: None=0, Low=1, Medium=2, High=3

Coral damage: Anchor				
Coral damage: Dynamite				
Coral damage: Other				
Trash: Fish nets				
Trash: Other				

Comments:	
Grouper sizes (cm):	
Bleaching (% of coral population):	
Bleaching (% per colony):	
Suspected disease (type/%):	
Rare animals sighted (type/#):	
Other:	

Notes: This form is a text version, and does not contain the formulae and macros used in the Reef Check data sheets at www.reefcheck.org (Data Recording)

Appendix 3.7.8 Example of field data sheet for filming of five replicate video transects.

Reef Name:		**SITE Code No:**		**Transect No.:**	1	**Obs:**	
Lat:		**Depth:**		**Date:**		**Temp sea:**	
Long:		**Visibility:**		**Time:**		**Tide:**	

Reef Name:		**SITE Code No:**		**Transect No.:**	2	**Obs:**	
Lat:		**Depth:**		**Date:**		**Temp sea:**	
Long:		**Visibility:**		**Time:**		**Tide:**	

Reef Name:		**SITE Code No:**		**Transect No.:**	3	**Obs:**	
Lat:		**Depth:**		**Date:**		**Temp sea:**	
Long:		**Visibility:**		**Time:**		**Tide:**	

Reef Name:		**SITE Code No:**		**Transect No.:**	4	**Obs:**	
Lat:		**Depth:**		**Date:**		**Temp sea:**	
Long:		**Visibility:**		**Time:**		**Tide:**	

Reef Name:		**SITE Code No:**		**Transect No.:**	5	**Obs:**	
Lat:		**Depth:**		**Date:**		**Temp sea:**	
Long:		**Visibility:**		**Time:**		**Tide:**	

Appendix 3.7.9 Example of scuba-swim REA field data sheet.

SITE No.:	Reef Name:		Date:
Lat.:	Depth:	Tide:	Obs.:
Long.:	Visibility:	Time: Photo:	
Map & profile			

Depth (m)		Benthic cover: rank % of total 100							Substratum rank: % of total 100					
max	min	HS	HC	DC	SC	TA	MA	CA	CP	LB	SB	RBL	SN	SLT
Slope	Reef dev..	Tot. Bleach	Part. Bleach	Expo -sure	Notes									

Key and notes:

Benthos

- HS – hard substrate
- HC – hard coral
- DC – dead standing coral
- SC – soft coral
- TA – turf algae
- MA – macroalgae
- CA – coralline algae

Substrate

- CP – continuous pavement
- LB – large blocks (> 2 m diameter)
- SB – small blocks (< 2 m diameter)
- RBL – coral rubble
- SN – Sand
- SLT – Silt

Cover data are recorded as ordinal rank categories (0–5).

4

SEAGRASSES AND SEAWEEDS

4.1 INTRODUCTION

4.1.1 A brief history of research on seaweeds and seagrasses of the region

The Red Sea has been a region of natural history exploration by European scientists for more than 200 years. Previous to the completion of the Suez Canal in 1869, travellers generally started their journeys of exploration from one of two points. From the east coast of Egypt (usually Suez), they could travel by vessels to the Arabian coast and then on to the Ethiopian coast, or they entered the Red Sea from the south, through the Strait of Bab el Mandeb, coming by ship via the Cape of Good Hope. After the completion of the Suez Canal many expeditions passed through the Red Sea on their way to other parts of the Indian Ocean. During that time numerous marine algae were collected, resulting in the description of many species with the Red Sea as type locality. A historical review of phycological research in the Red Sea is given by PAPENFUSS (1968). The first record of marine algae from the Red Sea dates back to 1756, and since then there have been a number of important contributors to the knowledge of the marine algae of the Red Sea. These include Forsskål (18^{th} century); Turner, Delile, Lamouroux, Decaisne, Agardh, Montagne, De Notaris, Zanardini, Piccone, Hauck, and Bornet (19^{th} century); Reinbold, Lyle, Christensen, Børgesen, Nasr, Newton, Rayss, and Dor (20th century). A milestone in macroalgal research in the Red Sea was the catalogue and bibliography of the Red Sea benthic algae, compiled by PAPENFUSS (1968). Recent studies include WALKER (1987) and ATEWEBERMAN (1997). PRICE et al. (1988) studied the ecology of seagrasses in the Red Sea. Global taxonomic and biogeographical studies on seagrasses have been carried out by DEN HARTOG (1970) and PHILLIPS & MEÑEZ (1988).

Very little is known about the seaweeds and seagrasses of the Gulf of Aden. ORMOND and BANAIMOON (1994) investigated the ecology of intertidal macroalgal assemblages on the Hadramaut coast of southern Yemen. This study resulted in a list of 163 taxa of seaweeds. WYNNE and JUPP (1998) compiled 74 new records of benthic marine algae for the flora of Oman. More recently, the United Nations Development Programme (UNDP) has become involved in the conservation and sustainable use of the biodiversity of the Socotra Archipelago (UNDP/GEF Project YEM/96/G32). The seaweeds and seagrasses of these islands have been studied by LELIAERT (1999), SCHILS (2000), WYNNE & LELIAERT (2000), SCHILS (2002), SCHILS & COPPEJANS (2002, 2003a, 2003b), SCHILS et al. (2003a, 2003b). The seaweeds and seagrasses of the north coast of Somalia remain largely unstudied.

4.1.2 An overview of the significance of seaweed and seagrass communities in the region

Seaweed communities

Seaweeds can grow as individuals, but they more frequently live together in communities with other seaweed and animal species. Seaweed communities affect and are affected by the environment and are some of the most productive marine plant communities in the world. Together the intertidal and subtidal zones give rise to a narrow coastal area that accounts for less than one percent of the Earth's surface. However the productivity of this region can equal or exceed that of most terrestrial communities (DAWES 1998).

Several areas with hard substrate in the Red Sea and the Gulf of Aden are not dominated by corals but by macroalgal assemblages. Shallow coral reef areas of the northern and central Red Sea are often dominated by filamentous greens, small browns and tuft-forming red algae. In upwelling regions (e.g. south coast of Yemen) large brown algae may dominate. Perennial brown algae (such as *Sargassum*, *Cystoseira* and *Hormophysa*) are dominant over extensive parts of shallow hard substrata in the southern Red Sea. In most of these areas algal communities show a strong seasonality; many seaweed species appear to be annual. Seasonality is correlated with water temperature that, for the Red Sea, is coldest in winter but for the Arabian Sea, is coldest during the summer upwelling (SHEPPARD et al. 1992; BANAIMOON 1998).

Seagrass communities

Seagrass communities (also called seagrass beds or meadows) often characterise sandy and muddy biotopes. Seagrasses are monocotyledonous angiosperms adapted to marine life both through their physiology and morphology. The most obvious characters of seagrass species are the extensive rhizome and rooting systems, and the very flexible, generally strap-like leaves. Tropical seagrass beds on mud, sand or coral rubble can consist of a single species, but often contain members of different genera. According to some phytosociologists, seagrass beds are the most simply structured communities of rooted plants, as they are mostly composed of only one or a few rooting species. This often gives seagrass meadows a rather monotonous appearance. However, the structure of these apparently uniform seagrass beds disguises a great diversity of floral and faunal components. Seagrass ecosystems provide habitats for a wide variety of marine organisms, both plant and animal. These include meiofauna and flora, benthic flora and fauna, epiphytic organisms, plankton and fish, not to mention microbial and parasitic organisms. The relatively high rate of primary production of seagrasses drives detritus-based food chains, which help to support many of these organisms. Birds, fishes and turtles also directly consume seagrasses. Four main sub-habitats can be recognised in seagrass beds. These are:

- The leaf epiphyton, comprising the microflora with associated small animals, including nematodes, polychaetes and crustaceans, together with sessile fauna, such as hydroids and anemones, and larger animals, such as snails, echinoderms and small fish;
- Stem and rhizome biota, which include larger epiphytic algae, various polychaetes, amphipods and bivalves;
- Species swimming among the leaves including fish and crustaceans;
- Sediment fauna, although this may differ little from that of the surrounding benthos.

The distribution and complexity of seagrass habitats in the Red Sea and the Gulf of Aden is probably controlled by habitat availability and extremes of temperature and salinity. Seagrass beds develop to their fullest extent in the south of the Red Sea. This area is characterised by a wide and shallow shelf, a high prevalence of unconsolidated sediments, and low temperature and salinity fluctuations (SHEPPARD et al. 1992). Limited areas of dense seagrass beds have been recorded in the Gulf of Aden (HIRTH et al. in SHEPPARD et al. 1992).

4.1.3 Species recorded in the area

Seaweeds

The catalogue of the Red Sea benthic algae by PAPENFUSS (1968) contains more than 500 seaweed taxa. The proportion of species endemic to the Red Sea is about nine percent. On the other hand, 64 percent of the species are pan tropical. WALKER (1987) separated the known species into four geographical regions, the gulfs (i.e. Gulf of Aqaba and Gulf of Suez), northern, central and southern regions. He showed that the percentage of species known from the Red Sea that occur in any one of the four regions, was between 8% and 40%. Many of the southern species are typical of warm waters from the tropics, while the northern species include members typical of slightly cooler areas. The boundary between the two species assemblages is drawn approximately through the middle of the Red Sea. The seaweeds of the Gulf of Aden have been less well studied, especially from the north coast of Somalia. From the south coast of Yemen, 163 seaweed taxa have been recorded (ORMOND & BANAIMOON 1994).

Seagrasses

Ten species of seagrasses have been recorded from the Red Sea. These belong to seven genera, the total number known for the tropical Indo-West Pacific region. On the eastern Red Sea coast, seagrass assemblages have been identified from cluster analysis using species cover data (PRICE et al. 1988). At a broad level, this revealed three groupings separated by latitude, suggesting biogeographic trends. A more detailed study carried out in the southern Red Sea indicated six distinctive assemblages. Three of these were dominated by a single seagrass species (*Thalassia hemprichii*, *Halophila ovalis* and *Halodule uninervis*) (SHEPPARD et al. 1992).

4.2 METHODOLOGY

4.2.1 Qualitative assessment of the macroalgal and seagrass flora of an area

A qualitative assessment of the marine flora involves collecting specimens from a specific area, resulting in a list of species. Depending on the study, the coastal area can vary from small (e.g. a coastal band of 10 m, a rock outcrop, etc.) to large (e.g. one to several kilometres of coastline, or a small offshore island). The resulting species list is important for calculating biodiversity indices for the area. When comparing species numbers or biodiversity indices for different coastal areas, these areas should be of comparable size. A major disadvantage of qualitative collection data is that species abundance is not taken into account. This can be corrected, partially, by making the sampling method semi-quantitative. This implies that each species is ranked based on its abundance, evaluated by visual observations. An example of such a ranking is the Tansley scale (Table 4.1). The growth form (sociability) of seaweeds can also be taken into account. Here the Braun-Blanquet's sociability scale can be used for each species (Table 4.2).

Tansley scale	
d	dominant
c	co-dominant
a	abundant
f	frequent
o	occasional
r	rare
s	sporadic

Table 4.1 The Tansley scale, an indication of species abundance in a quadrat (quantitative sampling) or larger area (semi-quantitative sampling); after SCHAMINÉE et al. (1995) and SCHILS (2000).

Braun-Blanquet's sociability scale	
1	solitary
2	in small groups or tufts
3	in larger groups, cushions or humps
4	in mats or very large groups
5	covering approx. the entire quadrat

Table 4.2 The Braun-Blanquet's sociability scale for the indication of a species' life form; after SCHAMINÉE et al. (1995) and SCHILS (2000).

Field collecting (intertidal and subtidal) and preservation of marine plants

Extensive and well-prepared collections are the basis of all studies of marine organisms. The importance of good collections for taxonomic studies is evident, but it is equally important that representative collections – often referred to as 'voucher specimens' – be kept of each species recorded during an ecological survey. Without such specimens, there is little possibility of checking and confirming identification on the basis of names used in publications. Such specimens should be numbered, labelled, and deposited in a recognised herbarium (WOMERSLEY 1984).

Collecting. Intertidal habitats can be surveyed by wading during (extreme) low tide or by snorkelling at high tide. Subtidal collecting can be done by snorkelling or scuba-diving. For the non-diver, subtidal seagrass and algal beds can be sampled in calm waters (at least down to several metres) using a dredge. Whether making subtidal or intertidal collections, similar water-resistant equipment will be required. If wading, collecting shoes, or boots should be available. Many algae and some seagrasses can be removed by hand, but a scraper or a stout knife may be necessary. A spade is useful in seagrass beds. Some thick encrusting algae can be removed with a knife, but many (especially the crustose coralline algae) must be collected along with the substrate. This can only be done with heavy instruments such as a hammer and chisel. Specimens can be kept in a variety of field containers such as buckets, (zip-) bags, perforated plastic bags or mesh bags. Small plastic vials can be useful for minute specimens. The collected material should be kept in water to avoid decay by temperature rise or desiccation. Each container should be given a serial number on a water-resistant label, and recorded on a clipboard with waterproof paper or on a scuba-board. Ecological data (intertidal zone, substrate type (rock, epiphytic, sand, silt, etc.) and inclination (horizontal, vertical, overhanging) should be noted for each collecting site. Additional information on collecting seaweeds and seagrasses is given by DAWES (1998), TSUDA & ABBOTT (in LITTLER & LITTLER 1985), and WOMERSLEY (1984).

Preservation. Seagrass and algal specimens can either be preserved in formalin (wet preservation), or prepared on herbarium sheets (dry preservation). Each specimen to be preserved is given a serial number that corresponds with a number in a notebook. The notebook contains the data recorded with each specimen; this information is placed on the label at a later stage (see below).

Formalin is about 40% by volume formaldehyde, and is diluted 1/10 with seawater, giving a solution of 10% formalin or 4% formaldehyde (the concentration is not critical and half the above will usually give good preservation). Formalin is a strong irritant and carcinogenic so it should be handled with care, avoiding inhalation or direct contact with the skin.

Herbarium sheets can be prepared directly in the field using fresh plant material or in the laboratory using material preserved in formalin. The preparation of fresh material should be done as quickly as possible after leaving the field (preferably the same day) because seaweeds die off very quickly. The material is first sorted in plastic trays and complete specimens (including the holdfast and reproductive structures, if available) are selected for preparation. These plants are then mounted by “floating out”. The specimen is immersed in a tray with seawater and arranged with forceps on an immersed sheet of stiff herbarium paper on which the specimen number has been written in pencil. The herbarium sheet with specimen is removed horizontally from the seawater, drained of the surplus water and deposited on newspaper, covered by a piece of cloth and a newspaper again. A stack of herbarium sheets and newspapers is built up and placed in a plant press under moderate pressure. Adding corrugated cardboard between stacks of newspapers and specimens enhances drying. The newspapers must be changed at frequent intervals (twice a day) until the specimens are dry.

Labelling. Unless specimens are properly and accurately labelled, they are of little value. Data recorded with each specimen should include:

- The locality (latitude and longitude are useful, especially for remote sites);
- Ecological notes, including the zone (intertidal) or depth (subtidal), slope, exposed at low tide or submerged in an intertidal pool, type of substrate, degree of wave exposure, temperature, etc.;
- Notes on morphology such as colour and texture;

- Date;
- Collector name(s);
- Collector number.

Mounting dried specimens. The dried specimens are mounted on herbarium sheets of a standard format and the labels are added. Specimens that do not stick on the paper should be stuck with adhesive paper (not with adhesive tape or glue).

Identification of seaweeds and seagrasses

No marine flora guides exist for the study area, hampering identification of seaweeds. Some field guides from adjacent areas, which may be helpful to identify the seaweeds of the Red Sea and the Gulf of Aden, are: JAASUND (1976: Tanzania) and COPPEJANS et al. (1997: East Africa). Since 64% of the seaweed taxa in the Red Sea are pan-tropical, floras or field guides from other tropical or subtropical regions can be used, certainly for identification to genus level. These include guides prepared by ABBOTT (1999: Hawaii, red algae); COPPEJANS (1983: Mediterranean); CRIBB (1983: Australia, red algae); DE CLERCK & COPPEJANS (1996: Jubail, Saudi Arabia); LAWSON & JOHN (1987: West Africa); LITTLER & LITTLER (2000: Caribbean); SILVA et al. (1996: Indian Ocean); TAYLOR (1960: tropical eastern coast of America); TRONO (1997: Philippines).

Seagrass identification can be carried out with DEN HARTOG (1970) or PHILLIPS & MEÑEZ (1988).

4.2.2 Remote sensing combined with ground-truth observations (phytosurvey)

Survey techniques include creation of landscape and vegetation maps through remote sensing (aerial photography or scanning systems) and ground-truth observations. Surveys are particularly useful for the study of large areas (e.g. kilometres of coastline). The procedures are simple and yield repeatable results in studies of seaweed and seagrass communities. Ground-truth observations can be carried out by qualitative or quantitative assessment of the marine flora of the area. Quantitative assessment is carried out using sample plots that are selected along the coast based on visual observations. The combination of remote sensing and ground-truth observations offers information for the creation of vegetation maps. A concrete example is given in DAHDOUH-GUEBAS et al. (1999).

Remote sensing

Remote sensing uses sensors to identify or measure parameters of an object according to variations in the electromagnetic radiation (EMR) reflected or emitted by the object. EMR can be natural, either reflected radiation from the sun or emitted heat from the earth. It can also be man-made such as a radar system. The wavelength of electromagnetic radiation spans many orders of magnitude and is conveniently divided into several arbitrary regions (e.g. ultra-violet, visible, near infrared, infrared, etc.). The amount and type of radiation reflected or emitted depends upon incident energy (e.g. thermal radiation) and the nature of the earth's surface. Remote sensing can be carried out by aerial photography or scanning systems (airborne spectral scanners or satellite sensors). GUILLAUMONT et al. (1997) discuss spectral properties of seaweeds in their natural habitat and provide a critical review of sensors and data processing for remote sensing of seaweed communities. Methods for distribution and mapping of seagrass communities using remote sensing and ground-truth observations are dealt with by KIRKMAN in PHILLIPS & MCROY (1990).

Aerial photography. Aerial photography can be carried out from fixed-wing aircraft (light or medium altitude aircraft), or helicopters. Photography is carried out using several types of photographic emulsions simultaneously. Films are chosen according to their respective performances: colour and infrared for intertidal, colour for submerged areas, colour and false colour film for floating algae. Photographs have little spectral capacities (infrared and visible field). However, they provide high spatial resolution, allowing texture analysis and good geometric quality.

Airborne spectral scanners. Image spectrometers have a good to excellent radiometric and spectral resolution but are much more expensive than photographic systems. They are also more expensive and complex to use over large regions than satellite data.

Satellite sensors. Satellite imagery provides reliable synoptic information reaching the user cheaply at regular intervals. It is a consistent and repeatable method. Historical data are available since the 1970's. Radiometric calibration can be produced in good conditions. However, satellite sensors have limited performance in seaweed studies because of their low spatial and spectral resolution, frequency and sensitivity. Moreover, bands are not optimal for underwater studies.

Data acquisition

Qualitative images obtained from the methods discussed above need to be transformed to quantitative information. This requires measurement of the areas covered by the various identified populations. Different techniques have been developed. Classical methods, such as manual measurement of the areas covered by the various identified populations, are time consuming. Other methods include planimeter methods, grid count methods and scannerisation. GUILLAUMONT et al. (1997) have reviewed data processing techniques. The most significant advances in the use of remote sensing data are in the field of Geographical Information Systems (GIS).

Ground-truth observations and creation of vegetation maps

Once aerial photographs have been examined, some form of ground-truth survey must be carried out. Ground-truth observations can be conducted through qualitative or quantitative assessment (or a combination of the two) of the marine flora of the area. Qualitative assessment implies general collection over a large area: several metres to kilometres of coastline. Quantitative assessment implies selecting sample plots (1–10 m^2) along the coast (DAWES 1998). The choice of location of the sample plots is determined by the data from the remote sensing. In these sample plots each dominant species is ranked for abundance, cover, and growth form (see 4.2.3. investigation of spatial community variation – quadrat sampling). The combination of data acquired from remote sensing and ground-truth observations can then be used to draw up vegetation maps.

4.2.3 Quantitative sampling methods

Investigation of spatial community variation

Transect sampling. Transects are used in plant zonation studies of intertidal communities (seaweeds) or where line quadrats are used (across seagrass beds). Stakes are aligned from the highest to lowest zone and a metric tape stretched between them. Samples for identification can be taken along the transect in each zone, or at every unit of measurement (every centimetre to every few metres, depending on the slope and detail required). Percent species is determined by dividing the number of individuals within a zone, by the total number present along the entire transect. Percent species cover is calculated by dividing the length (in centimetres or metres) of the transect (or zone) species cover by the total length of the transect (or zone).

Quadrat sampling. Measurements of unit-area can be done using quadrats ranging in size from 25 cm^2 to 1 m^2 squares; larger or smaller areas can be used according to the community structure and the accuracy required. Determination of the quadrat size is crucial. The frame size is a reflection of the size of the patches in the population. For instance, if seagrass shoots or seaweeds are clumped in 1 dm^2 patches, frames considerably larger (e.g. 1 m^2) should be used to ensure the inclusion of several patches. Quadrat frames can be easily and inexpensively constructed from plastic pipe (PVC works well). Quadrats may be subdivided if detailed sampling is required. Quadrat samplers are useful to determine changes in species composition in areas with major shifts in abiotic factors (e.g. a temperature gradient along a stretch of coastline). They can also be used in zonation studies to develop a more accurate determination of percentage cover, frequency and abundance.

To avoid bias in sampling, random or haphazard methods can be used for quadrat placement. Figure 4.1 shows a fictional example of a sample strategy to determine changes in species composition along a stretch of coastline. Quadrats can also be placed at regular intervals along each transect.

Species abundance in each quadrat can be determined in a number of ways:

- counting individuals of each species,
- estimating cover of each species, or
- determining biomass (standing crop).

Other vegetation parameters that can be recorded for the species in a quadrat are sociability and phenology. For sociability, the Braun-Blanquet's sociability scale can be used (Table 4.2). The phenology of a species can be indicated as: g = germling, v = vegetative, f = fertile (if possible with indication of the life stage), dis = old thallus parts remain, dth = thallus almost vanished.

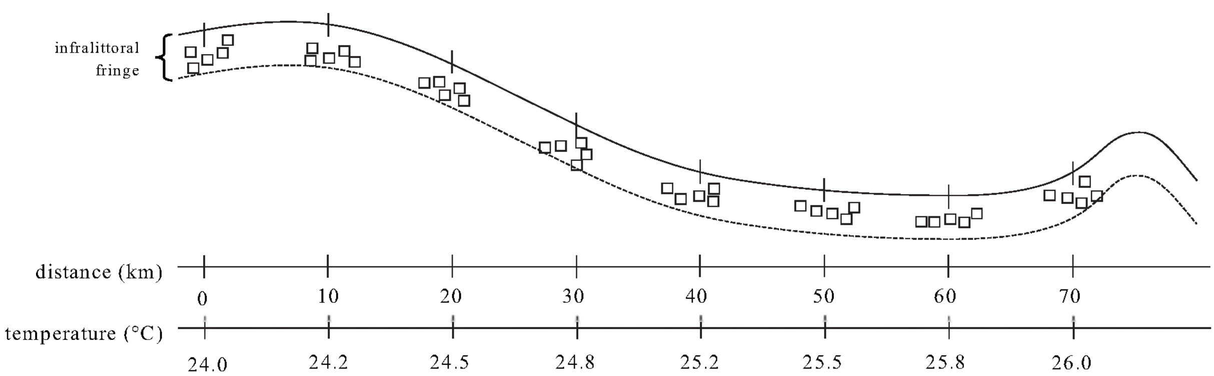

Figure 4.1 Fictional example of a sample strategy to determine changes in species composition along a stretch of coastline. Every 10 km, 5 quadrats (1 m^2 each) haphazardly placed in the infra-littoral fringe are examined. See text for explanation.

Counting the number of individuals of each species can be problematic; in many algal species individuals cannot be distinguished as they grow in a diffuse manner forming algal tufts. Counting the number of individuals in seaweed communities should only be considered with large distinct species, e.g. large browns. Instead of absolute numbers, a scale, e.g. the Tansley scale (already mentioned in 4.2.1) can be used (Table 4.1).

In seagrass communities, species abundance is often determined by estimating the number of seagrass shoots in a quadrat.

Shoot density refers only to the above ground, leafy portions of the plant. The density of roots is correlated to the density of shoots, but due to difficulty in measurement, is seldom quantified. Both destructive and non-destructive means of estimating shoot density can be used. A destructive technique commonly used involves clipping a quadrat of shoots at the sediment surface and measuring leaf surface area in the laboratory. The advantage of using destructive sampling is that samples can be processed in the laboratory and leaf area (see *leaf surface area* below) and biomass determination (see below) can be conducted on the same sample. Non-destructive estimates of shoot density allow for minimal perturbation of the meadow, which is useful for repeated sampling (see *investigation of temporal community variation* below). Counting shoots within a quadrat can be accomplished at low tide in intertidal meadows and with scuba equipment in subtidal meadows (DENNISON in PHILLIPS & MCROY 1990).

Percentage cover can be estimated using broad categories (e.g. a Braun-Blanquet's scale, Table 4.3). Seaweed communities are often characterised by different layers of algal growth forms: e.g. crustose species, an algal turf layer overgrown by a layer of larger foliose or filamentous algae, overgrown by large fucoid algae or kelp. In such a case the percentage cover of species is somewhat more complicated to estimate. Moreover the total cover (i.e. the sum of all species cover in a quadrat) can exceed 100%. Cover estimates can also be applied in seagrass beds but the estimation of shoot density is more widely used (see above).

Braun-Blanquet's combined estimation		
	No of individuals	**Cover**
r	very few	<5%
+	few	<5%
1	numerous	<5%
2	very numerous	>5%
	or arbitrarily	5 - 25%
3	arbitrarily	25 - 50%
4	arbitrarily	50 - 75%
5	arbitrarily	75 - 100%

Table 4.3 Braun-Blanquet's combined estimation of species abundance and cover; after SCHAMINÉE et al. (1995) and SCHILS (2000).

Species abundance can also be determined by biomass or standing crop measurements. There are a number of ways of expressing biomass or standing crop: wet weight, dry weight, weight of organic carbon or inorganic nitrogen.

The most widely used unit is dry weight in g/m^2. Dry weight of seaweed and seagrass species can be determined by oven-drying the specimens at 70°C for 72 hours. To allow comparisons, this unit should be given whenever possible, specifying whether it applies to pure stands or to a larger area including bare substrate patches. In the latter case, the percentage-cover of the seaweed or seagrass bed in the area considered should be noted. If only wet weight can be determined routinely, at least one series of wet weight/dry weight (wwt/dwt) correlations per dominant species should be made, since this ratio may vary considerably between different seaweed and seagrass species according to the texture of the plant tissue.

All data recorded in each quadrat should be written down in a standardised format. Table 4.4 shows an example of such a data entry form.

Specific techniques for the investigation of seagrass communities

Root/shoot ratios (R/S) (FONSECA, THAYER & KENWORTHY in PHILLIPS & MCROY 1990). The R/S ratio has been used

Date	***Hour***	***Tidal coefficient***	
Place		***GPS position***	
Quadrat No.	***Depth***	***Intertidal zone***	***Photo***

No	***Species***	***Br.-Bl.***	***Phen.***	***Soc.***	***Tans.***	***w.w. (g)***
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
etc						

Animals:

Additional observations:

Sal.	***Temp.***	***Nutrient container no.***
Secchi	***Slope***	***Sand cover***

Table 4.4 Example of a macroalgal vegetation sampling sheet. Species cover is estimated and wet weight is determined in the field. Some environmental variables are measured on site and a sample of seawater is collected for nutrient analysis. Br.-Bl.: Braun-Blanquet's combined estimation (Table 4.3); Phen.: phenology; Soc.: sociability (Table 4.2); Tans.: Tansley scale (Table 4.1); w.w.: wet weight in grams; Sal.: salinity measured with a refractometer; Temp.: temperature measured with a glass thermometer; Secchi: water transparency (in cm) measured with a Secchi disc; Slope: estimation of the slope in degrees; Sand cover: estimation of the percentage sand cover in the quadrat; after SCHILS (2000).

operationally to include both root and rhizome components. R/S ratios are relatively simple to measure and enhance estimates of total production by seagrass species. R/S ratios should be derived from plant material separated into shoot and root (plus rhizome) components at the meristem where cell differentiation occurs. R/S ratios are usually presented on a weight/weight basis, although area and volume ratios can also be determined. Weight data should be presented on an ash-free dry-weight basis, since inorganic contamination may account for up to 50% of the dry weight. The leaves and roots should be placed in 5% phosphoric acid for 10–15 minutes to remove carbonates and encrusting epiphytic organisms, and then rinsed in tap water. Plant components should then be dried in an oven at 80°C. Subsamples of the dried plant material should be ashed at 550°C for 4–6 hours to determine ash-free dry weight (AFDW). Field methods for R/S collections may vary depending on the required precision and accuracy. Clipping shoots out of a quadrat at the sediment surface will suffice for above-ground estimates. Running a sharp blade around the inside edge of the quadrat and harvesting the portions of the plant in the sediment provides the below-ground part for the ratio. This method may well leave some deeply rooted material behind (e.g. *Thalassia* roots can extend 4 m into the sediment). Usually, however, the majority of root and rhizome is found in the upper 20–40 cm of the sediment.

Wide variations in the R/S ratio occur among habitats as well as throughout the year. These are related to seagrass development processes and to prevailing environmental conditions. Seasonal changes in weight also occur. Hence, there is an age-dependent mechanism contributing to the rate, proportions and mass of observed R/S ratios, causing these values to change with time.

Static measures (one point in time) of seagrass R/S ratios can be used to assess the degree of development of a seagrass system. Because some seagrass components take a long time to decompose, it is necessary to quantify living versus dead material. An older seagrass meadow generally has a lower ratio of living to dead seagrass components (especially roots and rhizomes). For foliar portions, a visual examination of the shoot will suffice to distinguish living green blades from dead ones. For roots and rhizomes, a visual plus a physical examination is needed. Most roots decompose relatively quickly compared with rhizomes and will no longer appear white or succulent after senescence. Rhizomes may appear to be intact, but flexing the rhizome to the point of breaking should produce a brisk snap if it is still alive.

Leaf surface area (BULTHUIS in PHILLIPS & MCROY 1990). The leaf area of seagrasses in a quadrat must be known in order to calculate the leaf-area index (one-sided leaf area per unit ground area), and to calculate photosynthesis (moles of carbon or oxygen per unit leaf area). Leaf area can be measured directly using an area meter, planimeter or digitiser, calculated from length, width and diameter measurements. The easiest and most accurate method of measuring leaf area, irrespective of whether leaves are linear or irregularly shaped, is by using an area meter (e.g. LICOR LI–3100). This instrument is an automatically integrating planimeter developed for measuring leaves. If an area meter is not available the alternative method chosen depends on leaf shape and the number of leaves to be measured. Most seagrasses have flattened, linear leaves so that leaf area can be estimated by measuring length and width. The width is measured at three or more locations along the leaf. The area is calculated by multiplying length by mean width.

Leaf production (DENNISON in PHILLIPS & MCROY 1990). The principal methods of measuring leaf production are by change in standing stock over time and by leaf-marking techniques. The first method is problematic with seagrasses because of their perennial growth and the loss of leaf material during growth due to rapid leaf turnover.

Leaf-marking techniques can be used to distinguish leaf tissue formed before and after marking due to the growth form of seagrasses. Seagrass leaves have a basal meristem, which is near the sediment surface for most species. Above this region of dividing cells is a region of elongating cells, which are usually protected by leaf sheaths. Above the dividing and elongating cells, leaf tissue moves away from the basal meristem as long as leaf growth occurs, even though no cell division or elongation occurs in this region. Hence, the distance between the basal meristem and leaf marks made above the region of cell elongation can be used as a measure of leaf growth. Several techniques of leaf marking have been employed. One method involves stapling individual leaves. This marking technique is fast and easy but requires relatively large leaves. Several modifications of the staple technique have been developed for seagrasses with small leaves. A small wire inserted into the leaf, hole punches, or a water-insoluble pen can be used to mark seagrass leaves (Figure 4.2). Marking with a pen has the advantage of minimal damage to the leaf. The time interval between marking and collection is constrained by the growth rate of the plant, and the leaf turnover time sets the upper limit.

Several leaf production values can be calculated from leaf-marking techniques. Leaf material can be separated into leaf tissue produced before (above mark) and after

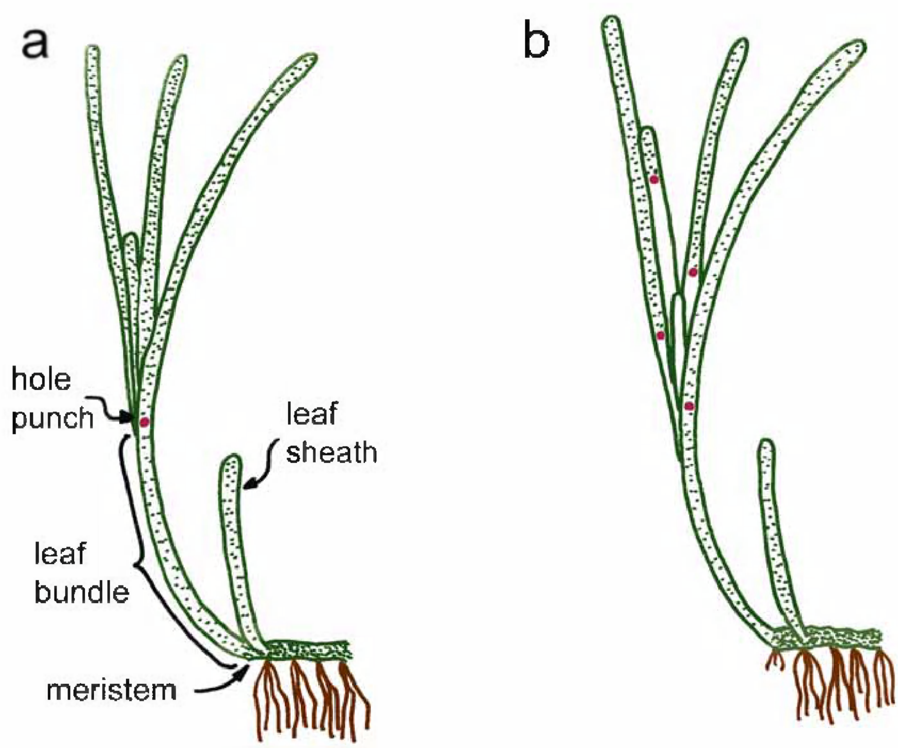

Figure 4.2 Hole-punch method of leaf marking in which a syringe needle hole is created several centimetres above leaf bundle (a) and the resultant scars used to distinguished leaf tissue which arose from the leaf before (stippled) and after (unstippled) marking (b); after DENNISON in PHILLIPS & MCROY (1990).

marking (below mark and unmarked leaves), dried for 24 hours at 80°C and weighed. The ratio of leaf material produced after marking to that present before marking, divided by the time interval, yields a relative production rate (e.g. g g^{-1} day^{-1}). For each shoot the leaf material produced after marking divided by the time interval yields leaf production per shoot (e.g. mg $shoot^{-1}$ day^{-1}).

Investigation of temporal community variation

In order to investigate the temporal variation of seaweed and seagrass communities, permanent quadrats (PQ) can be used. The methods used in this survey technique are explained by POLDERMAN in PRICE et al. (1980). In principle, the procedures for a general survey (e.g. quadrat sampling as explained above) and for the monitoring of one particular station (permanent quadrat sampling) are the same, the difference being that the latter procedure is repeated at regular time intervals. The choice of time interval depends on the objective of the investigation. If, for example, the study is to determine seasonal changes in species composition, then the permanent quadrats should be examined at least once a month. Quadrats measuring from 25 cm^2 to 1 m^2 are placed in a homogeneous vegetation patch. The different measurements for species abundance used in the quadrat sampling can also be used here.

Primary productivity

In any study of seaweed or seagrass ecology or physiology, a measurement of fundamental interest is the primary production of the population or community. Carbon fixed in photosynthesis, and organic matter accumulated with plant growth, constitute the very basis for the seaweed or seagrass community, its physical structure, its food supply and its mineral cycle. Numerous techniques are available for measuring primary production. The oldest of these methods involves monitoring increase in plant biomass over a growing season. Direct measurements of changes in dissolved oxygen (O_2) and dissolved inorganic carbon (DIC) in water surrounding seaweeds or seagrasses have been used successfully for various macrophyte systems. The radioactive C14 technique has had widespread use for measuring seaweed and seagrass production. For a description of the different techniques to measure primary production we refer the reader to KEMP, MURRAY & MCROY in PHILLIPS & MCROY (1990); ARNOLD & LITTLER in LITTLER & LITTER (1985); and KENNISH (1989).

4.2.4 Measurement of environmental variables

Water temperature

It has been shown that individual seaweed species distributions over a biogeographic scale are overwhelmingly limited by seawater temperature regimes. In the ideal situation, temperature should be recorded continuously or several times a day in order to calculate minimum, maximum and average temperatures per day, month and year. If daily temperature recording is not possible, it should be recorded at regular time intervals (e.g. once a month) over several years. Temperature varies with water depth, currents and waves, the amount that seaweeds or seagrasses retard water motion, as well as with local insolation. It is recommended that the temperature be measured near the substrate at different water depths. Temperature should be recorded using the Celsius scale. A glass thermometer, protected in a steel case, can be used for these measurements. For many studies, combination sensors recording temperature as well as salinity or conductivity simplify *in situ* measurements.

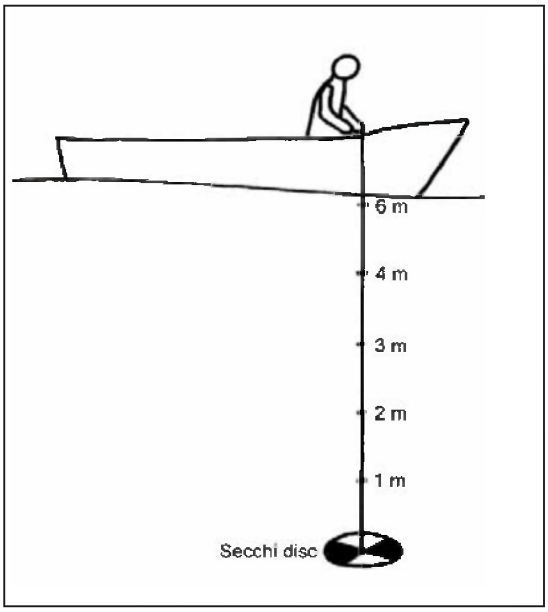

Figure 4.3 Use of a Secchi disc to measure water transparency. The Secchi disc is lowered in the water until it disappears from the view of a human observer. This depth is a measure for water transparency, which is in its turn a measure for light penetration to the bottom.

Light

The measurement of the sun's energy for photosynthesis is complex under any circumstances. The complexity is compounded when the light is filtered through water. Different measurement techniques (such as Secchi disc measurements, hours of daylight, total solar radiation and total irradiance under water) can be used in combination. The simple long-standing Secchi disc method measures the depth at which light, reflected by the Secchi disc, disappears from the view of a human observer as the disc is lowered into the water (Figure 4.3). Measurement of the hours of daylight are useful when making comparisons over many years of overall light conditions that may have contributed to the presence, growth, or disappearance of a seaweed or seagrass bed. Total solar radiation is measured on land, usually with a pyrhelliometer. Daily measurements may be available from a nearby installation, such as a marine station. To relate these data to underwater measurements, conversion factors may be derived by taking a number of simultaneous readings above and below the water. Total irradiance under water is measured by immersing a radiometer or quantum meter at the appropriate depth.

Shore height

Shore height above the low water mark (mean or extreme low tide) is measured using a level meter (or theodolite) and a surveyor's rod (Figure 4.4). Height is measured relative to the low water mark on a specific day and time. These relative measurements have to be transformed to absolute measurements by using tide tables and curves. For example in Figure 4.4 the height of plot 1 relative to the extreme low water mark is $b - a^1 + c$.

Depth

Depth below low water mark can be measured using a depth sounder on board a vessel, or a depth meter while scuba-diving.

Sand inundation

Sand inundation can be determined by estimating the percentage of sand cover in a quadrat or by removing all sand in a quadrat and measuring the wet or dry weight.

Substrate

Seaweeds grow on different types of substrate including rock, fossil coral, or artificial substrates such as plastic buoys or wooden constructions. Type as well as texture of the substrate should be determined. Seagrasses grow on sand or mud flats. Here the substrate type is determined by measuring particle size. This is done by taking a core of the sediment, which is dried, and then sieved using a set of standard screens (0.063 mm to 2 mm pore size). Particle-size distribution is obtained by dividing the dry weights of each size class by the total dry weight of the sample.

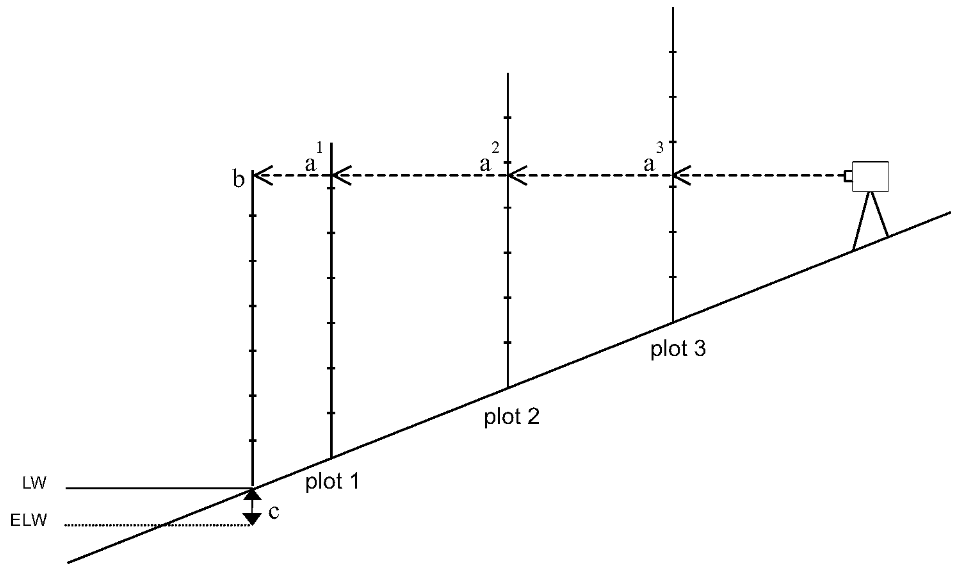

Figure 4.4 Use of a level meter and surveyor's rod to measure shore height above low water mark (LW); see text for explanation (ELW = extreme low water mark).

Slope

This should be measured in degrees: 0° (horizontal) – 90° (vertical) – 180° (overhanging substrate). Instead of numerical values, broad categories can be used (e.g. horizontal, sub-vertical, vertical, overhang).

Water movements

Waves, tides and currents can be important factors determining the structure of a seaweed or seagrass community. Different types of measurement include cumulative water motion, maximum force and continuous measurement of water velocity. An overview of techniques is presented by Denny in LITTLER & LITTLER (1985).

Salinity

Salinity can be measured using a refractometer. Refractometers are small and portable and give reliable readings. Measurements of salinity do not generally suffer from the daily variations experienced by water temperature except for smaller intertidal pools (evaporation versus rain). Rather, seasonal variation and changes associated with storm events are among the primary sources of variation to consider in designing a sampling protocol for a given site.

Nutrients

Four primary elements necessary for plant growth are oxygen, carbon, nitrogen and phosphorus. Nitrogen and phosphorus can be limiting nutrients to marine plants. Sample and analytic methods for determining nutrient concentration are elaborate and will not be discussed here. The reader is referred to WHEELER in LITTLER & LITTLER (1985) for a review of analytical techniques.

4.3 DATA ANALYSIS

Different sample methods require different analysis techniques. This section focuses on the analysis of data collected to assess structural patterns in seaweed and seagrass vegetation, and spatial or temporal community variation.

a)

	A	B	C	D	E	F	G	H	I
1		sample1	sample2	sample3	sample4	sample5	sample6	sample7	samp
2	Acrochaetiaceae sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
3	Acrosorium acrospermum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
4	Acrosorium maculatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
5	Acrosorium venulosum	0.00	0.00	0.00	0.00	0.00	0.00	0.01	
6	Aeodes orbitosa	2.67	7.46	0.56	0.13	24.11	7.42	0.00	
7	Ahnfeltiopsis glomerata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
8	Amphiroa ephedraea	5.14	1.47	10.70	0.72	26.00	26.50	0.10	
9	Anthophycus longifolius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
10	Antithamnionella tomentosa	0.00	0.00	0.00	0.00	0.00	0.01	0.00	
11	Apoglossum ruscifolium	0.01	0.00	0.00	0.00	0.00	0.00	0.00	
12	Aristothamnion collabens	0.01	0.01	0.01	0.00	0.01	0.00	0.01	
13	Arthrocardia corymbosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
14	Arthrocardia flabellata	0.00	0.00	0.05	0.00	0.00	0.10	0.01	
15	Bifurcaria brassicaeformis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
16	Bifurcariopsis capensis	80.20	0.00	67.52	0.66	0.00	0.00	0.00	
17	Botryocarpa prolifera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
18	Botryocladia paucivesicaria	0.02	0.00	0.03	0.00	0.00	0.00	0.00	
19	Botryoglossum platycarpum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
20	Bryopsis eckloniae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
21	Callithamnion sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.01	
22	Carpoblepharis flaccida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
23	Carpoblepharis minima	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
24	Caulerpa bartoniae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
25	Caulerpa filiformis	0.00	0.00	0.00	0.00	0.00	0.00	55.63	
26	Caulerpa holmesiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
27	Centroceras clavulatum	0.00	0.01	0.00	0.00	0.00	0.00	0.00	

b)

Microsoft Excel - Book4

	A	B	C	D	E	F	G	H	I
1		sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8
2	TMPW	14	14	14	14	14	14	14	14
3	TMPA	12	12	12	12	12	12	12	12
4	TMPC	10	10	10	10	10	10	10	10
5	SPNG	0	0	10	10	0	10	0	0
6	SAND	5	50	5	10	35	15	50	75
7	SLPE	0	0	90	90	45	0	0	0
8	GRAZ	0	0	0	0	0	1	0	0
9	EXPS	10	8	7	7	7	7	7	4

Table 4.5 Example of a matrix with species data (a), and environmental data (b), in an EXCEL spreadsheet. See text for explanation. In the second matrix abbreviations are used for the environmental variables: temperature variables (average temperature of warmest month, average year temperature, average temperature of coldest month) (°C), sponge cover (%), sand cover (%), slope (°), grazers (number of grazing animals), exposure rate.

4.3.1 Sample data input: spreadsheets and databases

In order to analyse collected data, it must be entered in a data matrix. This can be done in a spreadsheet or a database programme. In the case of quadrat sampling, sample plots are placed in columns and species in rows. The species abundance values can be presence/absence values, cover estimates, biomass data, etc. If environmental variables are incorporated in the analysis, they should be placed in a second matrix: sample plots in columns, environmental variables in rows. Table 4.5 shows an example of a species and environmental data matrix.

4.3.2 Preliminary data analysis: exploratory data analysis by means of descriptive statistics

Descriptive statistics can be defined as the enumeration, organisation and graphic presentation of data (data reduction). Preliminary data exploration can be done with a simple spreadsheet programme or with statistical programmes (e.g. STATISTICA®). Simple graphs can often clarify the large and disorderly amount of data. Questions that can be answered with descriptive statistics include: what are the dominant species; what is the distribution of the dominant species; what is the minimum, maximum, average and standard deviation of the environmental variables; which locations are species rich or species poor, etc.

4.3.3 Multivariate statistics

Studies in environmental biology usually involve more than one variable (e.g. large number of species, plots and environmental variables). Analytic techniques that deal with such kind of data are called multivariate analysis techniques or multivariate statistics. Techniques that are effective in revealing patterns in data (e.g. structural and distribution patterns) are ordination and classification. An overview of multivariate analysis techniques in vegetation studies is given by KENT & COKER (1992).

Transformation of data

The number of species is usually not evenly distributed over the plots. This is problematic for the implementation of statistical techniques. Transformation of data is a technique to correct this. Likewise, environmental variables can be transformed. The question of optimal transformation of species abundances in ordination has not yet been fully addressed. Techniques such as Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) appear to work well for raw data values (e.g. percentage cover, biomass, presence/absence data etc.) as well as for data values following logarithmic transformations, square root transformation, or transformation into a traditional cover-abundance scale. Apart from the problem of normal distribution of data, logarithmic and square root transformation are often used to dampen the effects of dominant species.

Ordination

Ordination is a widely used family of methods, which attempt to reveal the relationships between ecological communities. These multivariate techniques arrange sites along axes on the basis of species composition. The mathematical theory behind the different ordination techniques is quite complicated. A comprehensive overview of ordination techniques used in community analysis can be found in KENT & COKER (1992).

Indirect ordination methods arrange sites along axes only on the basis of species composition. Widely used methods in community studies are Principal Component Analysis (PCA), Correspondence Analysis (CA) and DCA. In direct ordination methods the arrangement of the sites is constrained by environmental factors, which are incorporated in the analysis along with the species composition. Widely used methods are CCA and Redundancy Analysis (RDA). The choice of environmental variables greatly influences the outcome of CCA and other constrained ordinations. For an exploratory analysis, one should certainly include variables that are related to the most important determinants of species composition. However, it is also often desirable to include other variables that are easy and inexpensive to measure – one may be surprised and find out that previously unsuspected factors are quite important in determining species composition (PALMER 1993).

The final result of an ordination is a two-dimensional diagram with samples, species and environmental variables plotted (Figure 4.5). In simple terms, samples that are grouped together are characterised by similar species composition and environmental conditions. Samples that are plotted far away from each other have very different species composition. Correlations can be examined between environmental variables, species and plots.

Numerical classification

Agglomerative methods (cluster analysis) proceed from individual samples or quadrats and progressively combine them in terms of their similarity in species composition until all the quadrats are in one group. The combinations are made by similarity coefficients that measure how alike any two quadrats are in terms of species composition or by dissimilarity coefficients that assess how unalike any two quadrats are. Different cluster methods are used in community studies: single-, complete-, and average-linkage clustering. A much-used similarity index in plant community studies is the squared Euclidean distance. An overview is given by KENT & COKER (1992).

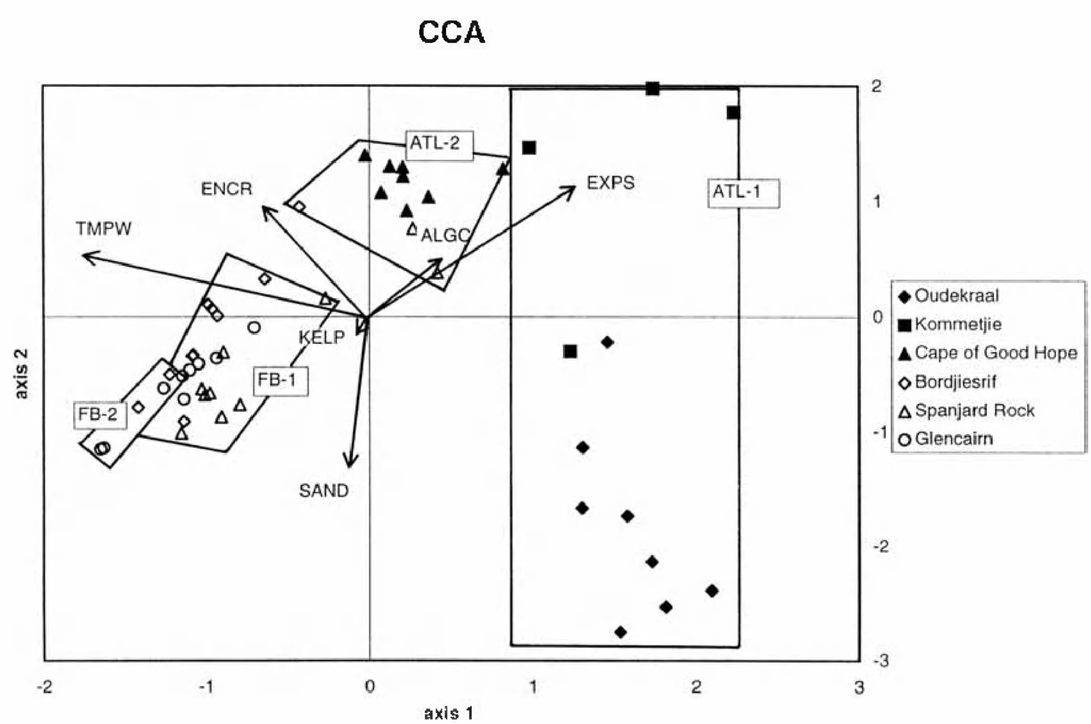

Figure 4.5 An example of an ordination diagram in a study of subtidal algal community variation; after LEILERT et al. (2000).

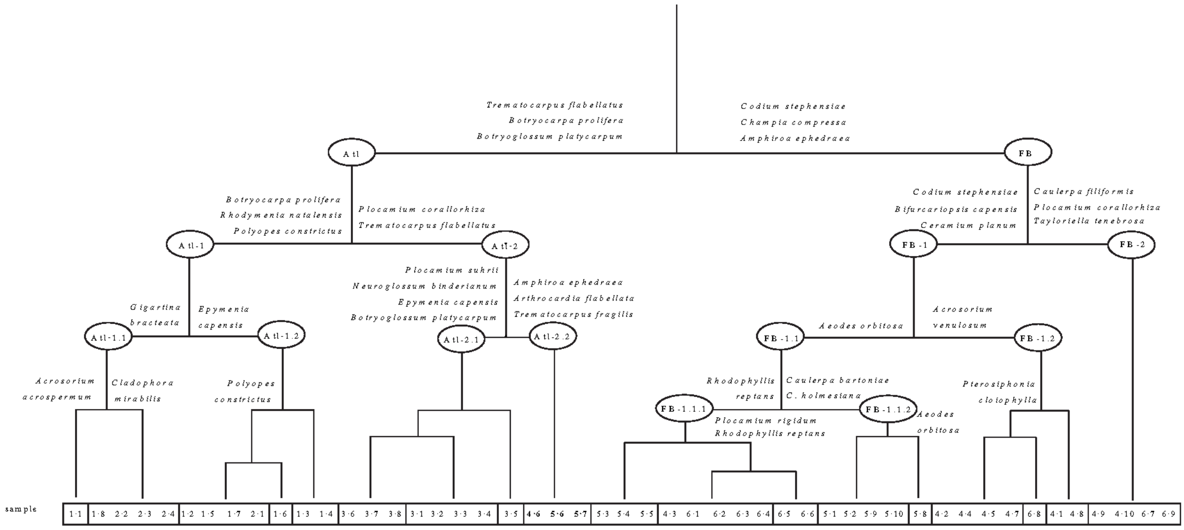

Figure 4.6 An example of a TWINSPAN classification using the same plots as in the ordination of Figure 4.5; after LEILERT et al. (2000).

Divisive methods start with the total population of individuals and progressively divide them into smaller and smaller groups. Two-way indicator species analysis (TWINSPAN) is now the most widely used technique for divisive classification in plant community studies. The method is based on progressive refinement of a single axis ordination from reciprocal averaging or correspondence analysis. The output of a TWINSPAN is a computer generated two-way table, which can be transformed into a classification (Figure 4.6). For each group of sample plots indicator species (i.e. species typical for a group of plots) are defined.

An overview of classification techniques used in community analysis can be found in KENT & COKER (1992).

When groups of plots can be clearly distinguished (from ordination and classification analysis), they indicate distinct community types, each being characterised by its typical species composition and environmental variables.

4.3.4 Calculation of species richness

Biodiversity indices are an overall measure of diversity that usually combine aspects of species richness and evenness. Species richness is the number of species in a given area. Evenness, or equitability, is the uniformity of abundance in an assemblage of species. Equitability is greatest when species are equally abundant. Two commonly used indices used to express biodiversity are the Simpson index and the Shannon-Weaver (Weiner) index.

Simpson's index assumes that the proportion of individuals in an area adequately weighs their importance to diversity. The equation for this index is:

$$D = 1-(\text{sum }(pi^2))$$

where D is the diversity and pi is the proportion of the 'i'th species in the total sample. Values for D can range from one to the total number of species (S). An index of one indicates that all of the individuals in the area belong to a single species. When D = S then every individual belongs to a different species and species are equally abundant.

The Shannon-Weaver index is very similar to the Simpson index, except for the underlying distribution. The Simpson index assumes that the probability of observing an individual is proportional to its frequency in the habitat whereas the Shannon-Weaver index assumes that the habitat contains an infinite number of individuals. The equation for this index is:

$$H = -\text{sum}(pi \ln(pi))$$

H is high when equitability and species number are high.

The terms alpha, beta and gamma diversity are used to refer to biodiversity on different spatial levels. Alpha diversity, or local diversity, is the diversity within a site or quadrat. Beta diversity is determined to measure the rate of species turnover between adjacent sites or areas. Beta diversity can be defined as a measure of how different (or similar) a range of samples are in terms of variety of species found in them (MAGURRAN 1988). A widely used method for measuring beta diversity using presence and absence data is the Wilson and Shmida measure, β_T:

$$\beta_T = [g(H) + l(H)] / 2\alpha$$

where g(H) is the number of new species encountered and l(H) the number of species which are lost along a transect; α is the average sample richness (i.e. average species number per area). A high β_T number indicates a high species turnover between adjacent sites. Gamma diversity or regional diversity is the diversity of a landscape, or all sites combined.

Different types of curves are utilised in the visualisation of species diversity. A species-individual curve is a plot of the cumulative number of species encountered, versus the cumulative number of individuals captured. A species-area curve is a plot of the (cumulative) number of species encountered, as a function of area. Species-area curves can be used to compare different regions.

4.3.5 Computer software

This section gives a short overview of existing software available for the above-mentioned analytic techniques.

Construction of data matrices

These can either be done in a spreadsheet or database programme. MICROSOFT EXCEL can be used as a spreadsheet programme, MICROSOFT ACCESS as a database. MICROSOFT EXCEL can also be used for exploratory data analysis (i.e. descriptive statistics and graphic presentation) and transformation of data.

Descriptive statistics and graphic presentation

These can be carried out with a large variety of statistical software packages. Two widely used programmes are STATISTICA and SPSS.

Ordinations

Ordinations can be carried out with the FORTRAN programme CANOCO (TER BRAAK 1988). This programme offers many possibilities but it is not easy to use. More recently, Windows versions of this program, which are much more user-friendly, have become available. A complete overview of ordination software can be found at *www.okstate.edu/artsci/botany/ordinate/software.htm*. Two software packages will be discussed below.

CANOCO FOR WINDOWS 4.5, developed by the Centre for Biometry, Wageningen, offers the same possibilities as the FORTRAN programme but is much easier to use. A disadvantage of CANOCO is that it cannot directly display ordination diagrams. Therefore another program: CANODRAW 3.1 is used. The software can be ordered from *www.microcomputerpower.com/cfw/*.

PC–ORD, a programme developed by Bruce McCune, offers a wide variety of multivariate statistical analysis methods for ecological communities, including cluster analysis, ordination, and species diversity. PC–ORD is an easy-to-use programme that directly displays ordination diagrams.

Cluster analysis

This can be carried out with statistical programs such as STATISTICA and SPSS. When using STATISTICA, cluster diagrams are directly displayed. A demonstration version of STATISTICA can be downloaded from *www.statsoftinc.com/*. A demonstration version of SPSS can be downloaded, from *www.spss.com/*.

Divisive classification

Divisive classification can be carried out with the FORTRAN programme TWINSPAN (HILL 1979). No Windows version of this programme is yet available.

TWINSPAN, written by Mark Hill, is a programme for classifying species and samples, producing an ordered two-way table of their occurrence. The two-way table generated by the programme has to be transformed to a classification by hand. The software package can be ordered from *www.ceh.ac.uk/*.

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5

Subtidal Habitats

5.1 INTRODUCTION

This chapter describes methods for the survey of benthic habitats and communities on both soft sediments (also termed unconsolidated substrates) and hard substrates, but specifically excludes seagrasses and coral reefs, which are dealt with in detail elsewhere in this guide.

These methodologies are largely based upon, or adapted from, English et al. (1997). However, it is notable that English et al. do not specifically address the survey of any subtidal hard substrates except for coral reefs. The survey methods for hard substrates presented here are adapted from a number of sources, including the coral reef survey methods of English et al. (1997), survey methods used by Sheppard & Salm (1988) for coral communities in Oman, and those of DeVantier et al. (1998) for coral reefs in the western Pacific.

5.2 GENERAL PRINCIPLES

The methods utilised for these two types of benthic habitat are very different, with those for soft sediments generally being carried out remotely using dredges and grabs, and those for hard substrates being carried out by divers using scuba gear or, occasionally, snorkelling equipment. General methods common to all subtidal surveys are considered below, whereas methods specific to either hard or soft substrate sites are dealt with separately at a later stage in this chapter.

The first step in any survey programme is a clear understanding of the objectives, as these will frequently determine aspects of the design of the survey, from large-scale considerations of site selection to details of equipment to be used.

5.2.1 Baseline surveys

All subtidal sampling programmes, and particularly those utilised for long-term monitoring programmes, require a knowledge of both the spatial and temporal variability of the communities under study. There is a general lack of detailed understanding of such variability in tropical soft-bottom communities and also in tropical non-coral reef hard substrates. Consequently, there is a need for baseline surveys of such habitats to provide an understanding of broad-scale variability in the survey area. Such baseline surveys should provide information about variability within and between different types of habitats (e.g. gravel, sand and fine sediment for soft bottom communities, or horizontal and vertical surfaces on hard substrates) and across environmental gradients such as depth.

5.2.2 Monitoring surveys

Having carried out baseline surveys to characterise the broad habitat and community types within an area, and to establish the nature and degree of biological variability, repeated surveys of the same sites within the area will provide information that can be used to monitor the effects of anthropogenic or natural impacts over time. Monitoring surveys will frequently require a more spatially intensive sampling regime within the survey areas, and greater replication of samples within sites, than baseline surveys.

5.2.3 Temporal variation

Temporal variation in natural communities should always be taken into account in both design of surveys and interpretation of results. The effects of seasonality vary greatly throughout the PERSGA region (see for instance SHEPPARD et al. 1992, pp. 121–140). The magnitude of seasonal effects in the northern Red Sea is minimal in comparison to those found in the monsoon upwelling areas of the eastern Gulf of Aden, but may nevertheless contribute significantly to natural variation in sampling results.

5.2.4 Pre-survey information search

When planning surveys, a search for relevant information already in existence should be carried out. This may provide valuable background information related to areas to be surveyed, and in some cases also historical detail of direct relevance. Potential sources to be researched include:

- Published scientific literature,
- Consultancy reports and other ‘grey’ literature,
- Maps, nautical charts and aerial photographs.

Of these, the existence and location of relevant maps, charts and scientific literature is relatively straightforward to establish. In contrast ‘grey’ literature and aerial photographs can be very difficult to identify and locate, largely because the distribution of such information is frequently limited or restricted and there are few or no central information sources related to them.

5.3 STANDARD METHODS FOR ALL SURVEY OR SAMPLING SITES

5.3.1 Recording site location

It is essential to record the locations of all survey and sampling sites accurately. The preferred basis for recording site location is latitude and longitude (hereafter referred to as lat/long). The existence of an accurate and precise lat/long is essential for:

- Mapping of sites and data, whether onto hard-copy maps or into computer-based Geographical Information Systems (GIS),
- Enabling repeated surveys of the same site. This is particularly essential for monitoring.

Hand-held Global Positioning Systems (GPS)

Ideally any field surveyor or survey team should have access to a hand-held Global Positioning System (GPS). These pieces of equipment are increasingly robust, accurate and reliable and provide a lat/long accurate to within 100 m or less. If a greater degree of precision is required than can be provided by a GPS then, once the site has been located by GPS, further precision can be achieved either by:

- Marking the exact position of the survey/sampling site with a buoy; useful when return to the site is required as in the case of monitoring surveys that need frequent re-sampling. (To reduce the chance of losing the buoy, it may be necessary to secure it slightly below the surface).
- Describing the areas in relation to readily visible distinctive features. This may be best achieved by the use of a hand-drawn and annotated map or diagram[1].

By its nature, a lat/long position records a point location. The linear nature of transects and sledge tows means that recording of such survey sites requires additional information:

- Record two lat/long positions, one at the start of the transect or tow and one at the end.
- Record the length and/or duration of transect/tow (usually recorded as duration and, if a tow, speed).
- Record the direction of transect/tow (a compass bearing, or a descriptive account such as ‘parallel to the shore’ or ‘along the depth contour’).

If a GPS is not available

If a GPS is not available, it is still possible to record site location in inshore areas precisely enough to enable accurate mapping and subsequent return to the site, if sufficient care is taken. This can be done by measuring and recording compass bearings to at least three prominent landmarks, to provide triangulation. The position of each site should then be mapped onto large-scale maps or navigation charts and the lat/long calculated as precisely as possible from the map or chart. This method is more time-consuming and

[1] Ensure that the features used in any such description are not of a type that may change position or disappear between surveys! For example, "Where the paved road ends and the dirt track begins" will not be useful if the paved road is subsequently extended. The same is true of "…exactly 30 m offshore from the high tide mark, directly south of the parked bulldozer" when the bulldozer may be driven away. (Both of these are genuine examples from survey record forms.)

generally less accurate than using a GPS, which remains the preferred method. If a GPS subsequently becomes available then sites should be re-visited to record their positions.

5.3.2 Recording ambient environmental parameters

Ambient environmental parameters describing prevailing conditions at a survey site should generally be recorded when a survey is carried out or samples taken. This is particularly the case for monitoring surveys, where ambient conditions may need to be taken into account in the interpretation of results.

Recording of many of these ambient parameters can in practice be impractical or impossible for a number of reasons, such as a lack of appropriate specialist equipment (e.g. oxygen meters, remote water sampling bottles) or a lack of opportunity (e.g. time of day and light requirements for Secchi disc). The most important parameter, depth, is fortunately almost invariably straightforward to measure and can be done without any specialist equipment. Other parameters should be measured when equipment and opportunity allow. When long-term environmental monitoring is to be carried out, then investment of resources in the purchase and use of the relevant specialist equipment becomes both more practical and more necessary.

Equipment

- Thermometer accurate to +/– 0.5°C for measurement of surface water temperature.
- Refractometer for salinity measurements and small plastic bottles for sampling of water at the surface (and at sampling depth, if diving is being carried out).
- Depth sounder or weighted shot line for measuring depth. Option: where diving is being carried out as part of the survey, the depth gauge of a dive computer is the preferred method for determining depth of sample site.
- Secchi disc for measurement of visibility (except at very turbid sites, this is only relevant to deeper sites).

Specialist equipment (not always available)

- Portable oxygen meter (splash-proof if possible!)
- Remote water sampling bottles (e.g. Nansen bottles, Figure 5.1).

Procedures

- Record the depth at the survey site either by depth sounder if available, or by weighted graduated line if not (if currents are present which pull the line to one side, so giving an over-estimation of depth, record this fact on the survey data form). At sites surveyed by divers, a diver's depth gauge or dive computer can be used. Note however that gauges or computers showing depth with a resolution of 10–15 cm (4–6 inches) are preferred, particularly at shallower sites.
- Read the water temperature 30 cm below the surface before sampling begins (this is the ‘surface’ water temperature).
- Use a small screw-topped bottle to collect a sample of water from 30 cm below the surface for salinity measurement using the refractometer. For surveys where diving is to be carried out the sample should be collected from the survey depth at the time of the survey, by one of the divers

carrying out the survey. Salinity measurements are particularly important in any area where freshwater input may be having an impact, or where evaporation in shallow semi-enclosed areas such as lagoons may increase salinity significantly.

- Measure the turbidity at the site with the use of a Secchi disc. This should be carried out within two hours of midday, with a cloudless sky. This requirement means that recording turbidity can be impractical or impossible to do at all survey sites.
- At soft-bottom sites, a sample of sediment should be collected by grab for grain size measurement at each sampling site. This sample should be from the top 1–2 cm of the sediment, rather than from a cross-section of different depths within the sediment.
- When a portable oxygen meter is available dissolved oxygen concentration should be measured. This parameter is of particular importance when surveying areas where organic enrichment or pollution may be present. Water should be collected from the surface and, when possible, the sample depth. Oxygen concentration should be measured immediately after the water sample is collected, minimising time for changes in temperature, exposure to air etc. to alter the oxygen concentration in the water.
- If diving surveys are carried out, divers should use small plastic sample bottles to collect water samples for salinity or oxygen measurements at the survey depth. When carrying out grab or dredge sampling this can only be carried out using remote sampling devices such as Nansen bottles, which can be lowered on a line and closed remotely when they reach the required depth. If these or similar devices are not available then these measurements cannot be taken.

5.4 SURVEY OF BENTHIC COMMUNITIES OF SOFT SEDIMENTS

5.4.1 Introduction

Soft bottom habitats exist throughout the PERSGA region, frequently closely associated with coral reefs or rocky habitats. As well as supporting diverse and distinctive benthic and epibenthic communities, such areas of unconsolidated sediments form an integral part of both local and broader ecosystems wherever they occur. Surveys of the fauna of soft sediment habitats are principally carried out for monitoring of environmental impacts and pollution, for which they can be a powerful tool.

Although the biological survey of soft-bottom habitats has been widely utilised for environmental monitoring in cold and temperate regions, it is relatively under-utilised in tropical regions (ALONGI 1990). Extensive and rapid coastal development and the occurrence of commercial benthic trawl fisheries throughout large parts of the region mean that there is an increasing need for monitoring of soft bottom fauna throughout the Red Sea and Gulf of Aden.

Two methods for quantitative or semi-quantitative sampling of soft bottom communities are described here: grabs and sledges. These are both remote methods in which the sampling is carried out from boats.

Sledges provide semi-quantitative and descriptive information about benthic communities, while grabs provide more quantitative sample data. Each of these two methods samples a different aspect of the benthic community and, if possible, an assessment of soft-bottom benthic communities should include both sampling methods. If this is not possible, then the use of one of these methods will still provide valuable information.

Both methods require the use of motorised boats and specialist sampling equipment. When the equipment is available they are straightforward to carry out, the equipment is robust and its maintenance is simple.

Both of these remote survey methods are destructive to varying extents and, as a result, may be unsuitable for use in certain locations (such as marine protected areas). The sledge in particular, which is towed behind a boat and impacts considerably larger areas of sea floor than the grab, is unsuitable for surveys of areas where communities of long-lived and fragile benthic organisms are known to occur such as hard and soft corals, whip corals and other large invertebrates. This is particularly the case for monitoring surveys, where repeated sampling is necessary. In such cases a decision must be made about the costs and benefits of carrying out sledge surveys, on a case-by-case basis.

Equipment needed

Equipment for fieldwork:

- Motorised boat
- GPS and/or compass
- Sample gear (sledge and/or grab)
- For grab samples: A hopper-type base for secure emptying of grab samples and a winch (motor-driven or manual), to raise and lower the grab
- For sledge samples: a sorting box (wood, plastic or metal, large enough to accommodate the entire width of the sledge's open end).

If washing/sieving is to be carried out on board the boat:

- Buckets or a seawater pump for washing of samples
- Sieves (5, 2, 1, and 0.5 mm mesh sizes)
- 10% formalin and 70% alcohol
- Containers for samples
- Sample/site recording sheets
- Sample labels and pencils.

Equipment for sorting of samples in the laboratory:

- Sorting trays
- Petri dishes or similar small sorting containers
- Binocular microscope
- Forceps
- Containers for storage of sorted samples.

5.4.2 The Grab

Target groups: non-mobile epifauna and shallow infauna; principally used for biological monitoring surveys (e.g. van Veen grab, Figures 5.2 and 5.3).

Advantages

- Quantitative sampling, particularly useful for monitoring programmes
- Relatively easy to use from a boat.

Disadvantages

- Can be difficult to use reliably in areas of coarse sediments, particularly those with large pebbles or rubble.

Procedures

- Grab samples for general characterisation are taken at regular intervals along transects running at right angles to the shore.
- For examination of the effects of specific point sources of impact, such as effluent outfalls, a grid is used to locate sampling points all around the source of the potential impact. Sampling may be more concentrated in the immediate vicinity of such an impact.
- A minimum of three grab samples should be taken at each station. If time and other resources permit (both in the field and for subsequent laboratory sorting, bearing in mind that sorting can be extremely time-consuming) the preferred sample size is five grab samples per station.
- Samples can be sieved on board the boat or after return to the shore. If not sieved immediately samples should be stored in seawater in the interim, in sealable buckets. It is essential that samples are sieved and placed in preservative on the same day that the sampling takes place. Store samples out of direct sunshine until sieved, to prevent overheating.
- Label samples clearly with date, site, sample number and replicate number as soon as they are removed from the grab and placed into any other container. This information should be written in pencil on waterproof paper and placed inside the sample container (if waterproof paper is not available, thin card or strong ordinary paper can be used instead). The date, sample and replicate number should also be written in permanent marker on the outside of the sample container. Ensure that this is done in a place where the chances of the writing being rubbed off are minimal, such as on the lid.
- Sieve the sample through the set of sieves, discarding run-off water and silt. (Use of a 0.5 mm sieve may prove impractical due to clogging. If this is the case it is acceptable not to use this smallest sieve size, so long as the method used is consistent throughout each survey, and between all surveys which may be compared with each other.)
- Preserve echinoderms, soft corals and sponges in 70% or 100% alcohol (100% for crinoids, brittlestars and sea cucumbers; then transfer to 70% once initial preservation is completed). Preserve all other material in 10% formalin for initial preservation. Formalin concentration can subsequently be lowered to 5% or 4%. A cut should be made in the body walls of large organisms such as sea cucumbers to allow entry of preservative to the body cavity. All preservation and sample storage should be in wide-mouthed airtight containers, preferably made of plastic for safety.

5.4.3 The Sledge

Target groups: benthic epifauna; principally used for baseline surveys and monitoring surveys (e.g. the Ockelmann sledge, Figure 5.4).

Advantages

- Samples a different component of the benthic fauna from a grab, so provides a complementary data set.
- A good method for initial characterisation of an area.
- Relatively large area of sea floor sampled means the dredge is more likely than a grab to provide a description of a site including locally rare taxa.

Disadvantages

- Can be unacceptably destructive if used in areas dominated by large and long-lived invertebrates and is thus inappropriate for repeated sampling and monitoring programmes in certain areas.
- Only provides semi-quantitative or descriptive data about a site.
- Being towed, the sledge can become caught on obstructions on the sea floor.

Procedures

- Tows for sledge surveys are carried out at regularly spaced intervals across a transect. The transect itself will usually be at right angles to the shoreline and so tows will be parallel to the shore. Transects are spaced along the shore at intervals determined by the size of the area to be surveyed and the amount of time and other resources available. Larger areas will generally be sampled at wider intervals. If the survey is designed to examine the impact of a site-specific activity then transects, and tows across transects, may be closer together nearer to the point of the impact.
- Carry out three replicate tows at each site.
- Speed and duration of all tows should be consistent (nominally about 2 knots, equivalent to a walking pace, and for 5 or 10 minutes).
- After completion of the tow retrieve the sledge and empty the contents into sieves placed on top of a sorting tray or box. Rinse with seawater to remove fine silt and place all specimens into sample containers with preservative. Larger specimens can be removed from the sieves and placed into separate containers.
- Label samples clearly with date, site number, sample number and replicate number as soon as they are removed from the sledge and placed into any other container. This information should be recorded both inside and outside the sample container in the manner described previously for grab samples.
- Sample specimens should be preserved in 70% or 100% alcohol, or in formalin, in the manner described previously for grab samples.

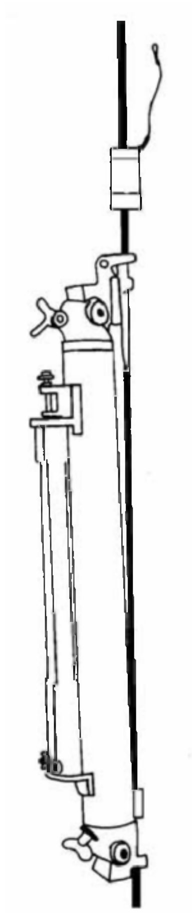

Figure 5.1 Nansen bottle

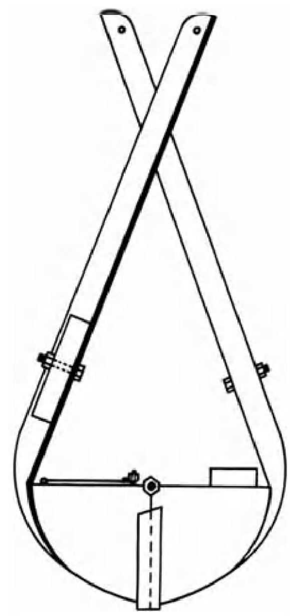

Figure 5.2 van Veen grab, closed

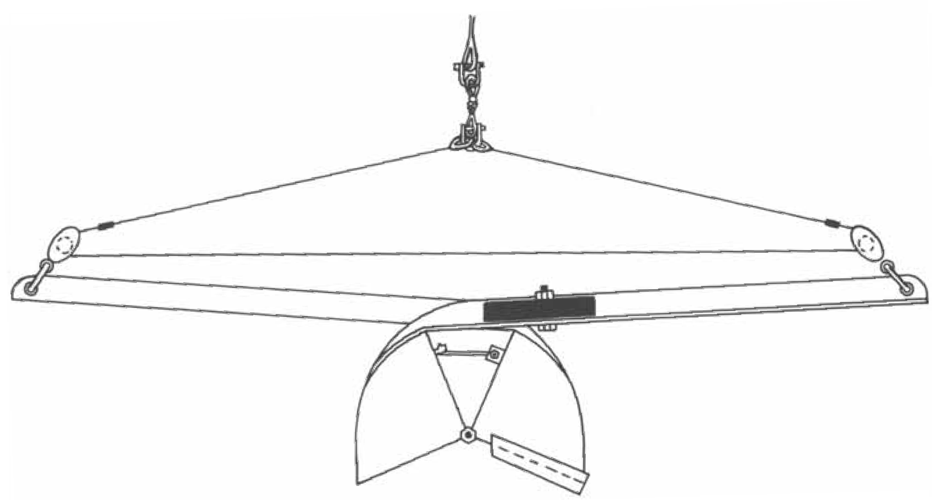

Figure 5.3 van Veen grab open

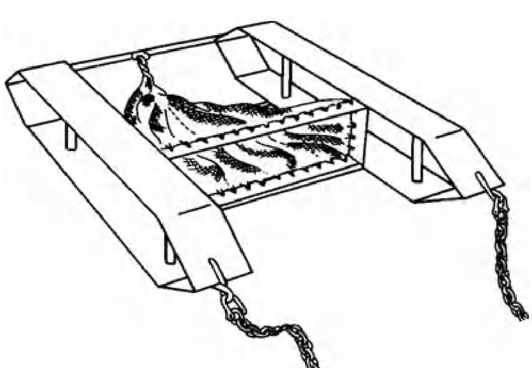

Figure 5.4 Ockelmann sledge

Figures adapted from ENGLISH et al. 1997.

5.4.4 Sorting of samples collected by grab or sledge

Samples collected by either of the above methods should be sorted in a laboratory. It is essential to minimise exposure of personnel to the fumes of preservatives, so those preservatives should be removed as far as possible before sorting is carried out. To do this:

- Pour off excess preservative through a fine-mesh sieve (as far as possible recycle all preservatives). In the case of formalin it is essential to dispose of any unwanted excess or waste safely. Do not simply pour down the drain.
- Thoroughly rinse the sample in clean fresh water or seawater to remove as much preservative from the sample as possible.
- Carry out sorting where there is a good circulation of air. The use of a fume hood for sorting is preferred, if one is available.

Once preservatives have been removed:

- Carry out gross-level sorting of samples in large plastic sample trays (preferably white) under good lighting. Remove larger specimens at this stage.
- Place sub-samples from material remaining in the trays into petri dishes, and sort into major classes under a binocular microscope.
- Subsequently sort to at least family level using taxonomic keys. (Sorting to species level is a time-consuming task. While sample sorting and identification should be carried out to species level if possible, where it is not possible sorting to family level is acceptable.)
- Data are recorded as counts for all organisms except colonial organisms such as corals, sponges and coralline algae. For these record wet weight for each family or species. For non-coralline algae also record wet weight of each species or group.
- Data are stored in hard copy on standard sample record sheets, which include all data on site number, sample number, date of collection, etc. Where possible data are also entered into a computer database for storage. Use of a database such as MICROSOFT ACCESS, which is compatible with programmes to be used for analysis, such as EXCEL or SPSS, is recommended.
- Do not discard samples after sorting. Instead store in formalin or alcohol, labelled with sample details on paper inside the airtight sample container and with permanent marker on the outside. If storage space is available it is recommended that samples be retained for at least two years in case re-examination is needed.

5.4.5 Data analysis for grab and sledge samples

A good summary of the communities within samples can be provided by simple descriptive analyses of data, including:

- Species lists
- Densities of species/families
- Distributions of species/families (best represented as a map or schematic diagram).

For examination of relationships between variables, both biological and environmental, simple correlations and regressions should be used. If in any doubt about whether there is a causal relationship, then correlations should be used.

Diversity indices usefully summarise abundance data sets of species, and of higher taxa such as families, to provide a single number representing a measure of diversity in a sample or at a site (see MAGURRAN 1988 for a comprehensive review of ecological diversity measures).

Two components of diversity are species richness (number of species) and species evenness (how equally abundant the species found in the sample are). In general, if a sample is heavily dominated numerically by one, or a few, species it will be less diverse than one in which abundances are more evenly spread between species. An abundance of diversity indices exists; these principally vary in how much weighting they give to one or other of these aspects of diversity.

One of the most commonly used measures of diversity in marine surveys and monitoring is the Shannon-Weiner index (H'), also known as the Shannon index. This index is dependent upon both the species richness of a sample and the evenness and so provides a useful combination of the two types of measure.

The Shannon-Weiner index (H'):

$$H' = \sum_{i=1}^{s} pi(\log 2\ pi)$$

where pi is the proportion of the i^{th} species (or other taxon such as genus or family) in the sample.

Multivariate analyses require specialist computer programmes, but they are powerful tools for revealing patterns in biological communities, and are commonly used to explore data sets, and to reveal similarities and differences between different sites, or changes within a site over time. A number of software packages have been developed that aid the application of multivariate analyses to environmental data, including some specifically designed for application to the study, survey and monitoring of marine ecosystems.

When appropriate software is available, cluster analyses and multi-dimensional scaling (MDS) analysis should be used to identify patterns of similarity and difference between samples and sites. The nature of those similarities and differences can then be examined in more detail if necessary.

5.4.6 Data presentation

Presentation of data about abundance, density, diversity and ambient parameters can be done in both tabular and graphical form and will provide a useful description of the sampled communities:

- Tables should be used where presentation of exact data values is required. This is frequently in addition to graphical representations.
- Graphical representation is particularly useful for presentation of descriptive parameters, such as differences between sites, or differences between different surveys of the same site. Both direct values, such as abundances, and derived values, such as diversity indices, can be plotted graphically.

Multivariate analyses are generally presented in formats specific to the analysis carried out (dendrograms, MDS plots, etc).

Representation of data through plotting onto maps can be an invaluable aid to both understanding and to decision making. A computer-based GIS is the preferred method for mapping (e.g. ARCINFO, or the PC-based ARCVIEW). In the absence of GIS facilities, use of hard copy maps with different overlays illustrating different parameters can also be valuable and productive.

5.5 NON–CORAL REEF HARD SUBSTRATE COMMUNITIES

5.5.1 Introduction

The PERSGA region is one of the most ecologically variable areas of the tropical Indo-west Pacific. This naturally occurring variability in shallow subtidal habitats manifests itself most conspicuously on hard substrates. Hard substrates within any large area of the PERSGA region may be dominated by:

1. Well-developed coral reefs (characteristic of most of the northern and central Red Sea), or
2. A combination of coral and algal reefs (characteristic of much of the southern Red Sea) or
3. A frequently very patchy combination of:
   - rocky substrates with little or no living coral (but often with high diversity of other benthic organisms, including both invertebrates and seaweeds),
   - rocky substrates with a variable cover of living coral, sometimes including more or less well-developed coral reefs.

   (both characteristic of the Gulf of Aden and Arabian Sea).

Within the PERSGA region, non-coral reef hard substrate habitats are largely confined to the Gulf of Aden including the Socotra Islands, and to the Arabian Sea coast of eastern Yemen. Here, non-coral hard substrates can be extensive wherever rocky shores occur and at offshore reefs, frequently forming a patchwork with areas of relatively high coral cover. (The term ‘reefs’ is used here to mean any area of raised hard substrate, whether composed either of corals or non-biogenic rock).

Globally, the study of the ecology and diversity of non-coral tropical reefs and hard substrates in category 3, above, is comparatively neglected. Studies in the northern Indian Ocean and Arabian region have been carried out in Oman and Sri Lanka (e.g. SHEPPARD & SALM 1988; GLYNN 1993; RAJASURIYA et al. 1998). These studies, however, have concentrated to a greater or lesser extent on the coral communities that are present, even at extremely low densities, on virtually all hard substrates in the region. Consequently the non-coral component of such communities is relatively poorly studied (the exceptions to this are macroalgal communities, which have been extensively studied in some areas).

Among the first to address this combination of different coral and non-coral hard substrates in the Arabian region were SHEPPARD & SALM (1988) in their study of the corals of Oman. Being principally a study of coral communities, they did not address in any detail the wider nature of communities living on non-coral hard substrates, but the paper does provide a useful basis for differentiating broad types of benthic hard substrate community found in the region. This differentiation is based on how dominant hard corals are at a site and how well developed coral reef structures are. The categories SHEPPARD & SALM (1988) identified on this basis are as follows.

Category A

Clear coral reef growth exists, where the bedrock is overlaid or obscured by the characteristic reef topography of a horizontal reef flat and a reef slope.

Category B

Coral framework is present in which corals provide a substrate cover of > 25%, and sometimes exceed 75%, but there is no reef topography. Instead gross substrate topography and slope remains unchanged compared to adjacent coast not colonised by coral.

Category C

Coral cover is < 15%, or too low to be considered as providing framework. Corals remain diverse but do not include more than scattered colonies of the main framework builders. All colonies are attached directly onto bedrock.

This section deals with hard substrate communities of type C. Types A and B are covered in the chapter which describes survey methods for coral and coral communities. Although categories B and C could theoretically grade into each other, in practice values for living coral cover tend to be widely separated into these two groups. Also see chapter on seagrasses and seaweeds for survey methods to be used specifically to provide descriptions of macroalgal communities.

5.5.2 Methods

The methods described here are principally based upon or adapted from those of ENGLISH et al. (1997), SHEPPARD & SALM (1988) and DEVANTIER et al. (1998).

For broad habitat characterisation surveys, and surveys which will not be used for monitoring purposes and so will not require return visits to exact locations, transects need not be marked permanently. If return to the exact place is required then the locations of survey sites must be marked in a manner that enables return to and re-survey of the exact site.

As a general rule, for surveys carried out by divers the number of different workers recording data should be kept to a minimum, both within one survey and for repeat surveys of the same areas, in order to reduce between-observer error.

Procedures

- Prior to carrying out any survey transects, a rapid assessment of the site is carried out to enable the site to be assigned to one of categories A, B or C as defined by SHEPPARD & SALM (1988). This assessment can usually be carried out without the use of scuba equipment. In most of the Red Sea this step may be unnecessary, as almost all shallow hard substrates here fall into Category A.
- For sites in categories A or B survey methods described in the chapter on corals and coral communities should be used.
- At sites falling into category C, a range of standardised depths is surveyed. If hard substrates are limited to shallow depths, then transects are

only carried out to the greatest standardised depth at which hard substrates occur. Standard depths are:

  - 1–2 m (snorkelled)
  - 7 m
  - 15 m

- Record the approximate mean depth along the transect at which hard substrates are replaced by unconsolidated substrates.
- Transects are standardised at 100 m long (equivalent to a 10 minute slow swim) and a nominal 4 m wide (estimated by eye, 2 m either side of the central line of the transect).
- The percentage cover of each of eight substrate categories and eight ecological categories (Table 5.1) are estimated by eye using categories of percentage cover (Table 5.2). Data are recorded onto prepared recording sheets if waterproof paper is available, or directly onto underwater slates.
- The abundances of each of 20 taxonomic categories (Table 5.3) are recorded using abundance categories (Table 5.2).
- Record all observed occurrences of coral disease, bleaching, crown-of-thorns starfish, *Drupella*, or high concentrations of sea urchins. When occurring within transects record the approximate percentage of coral colonies affected, or the numbers of starfish or urchins observed. Outside the transect record presence or absence. Note that crown-of-thorns starfish may occur even in areas of extremely low coral cover and may feed on soft as well as hard corals.
- Make a note of all observations of human utilisation and impacts at the site (e.g. fishing activity, litter, fish traps, lost nets, anchor damage, etc.).
- Data are stored in hard copy on standard sample record sheets, which include all data on site number, sample number, date of collection, etc. Where possible, data are also entered into a computer database for storage. Use of a database such as MICROSOFT ACCESS, which is compatible with programmes to be used for analysis, such as EXCEL or SPSS, is recommended.

5.5.3 Data analysis

Graphical representations of both substrate and taxonomic categories provide useful descriptive summaries and exploratory analysis of survey data.

When appropriate computer software is available, multivariate analyses are used to group transects and sites on the basis of the eight substrate variables recorded to provide general site descriptions. Finer resolution is obtained through carrying out similar analyses on the taxonomic data. The nature of the similarities and differences between groups of sites, and between times, can then be examined in more detail if necessary.

The groupings identified by multivariate analyses can be used to map distribution of habitat and broad community types.

5.5.4 Data presentation

Presentation of data about abundance, diversity and ambient parameters can be done in tabular or graphical form.

Graphical representation is particularly useful for presentation of descriptive parameters, such as differences between sites, or differences between different surveys of the same site. Both direct values such as abundances, and derived values such as diversity measures, can be plotted graphically.

Tables should be used where presentation of exact data values is required.

Multivariate analyses are presented in formats specific to the analysis carried out (dendrograms, non-scalar plots, etc.).

Representation of data through plotting onto maps can be an invaluable aid to both understanding and to decision making. A computer-based GIS is the preferred method for mapping (e.g. ARCINFO, or the PC-based ARCVIEW). In the absence of GIS facilities, use of hard copy maps with different overlays illustrating different parameters can be valuable and productive.

Substrate category	Ecological category
Rock (modern biogenic)	Hard coral (live)
Rock (non-biogenic or fossil)	Hard coral (dead)
Large blocks	Soft coral
Small blocks	Turf algae
Rubble (non-biogenic)	Kelps (*Sargassum* spp. etc.)
Rubble (coral)	Other macroalgae
Sand/gravel	Coralline algae
Silt/mud	Other invertebrates

Table 5.1 Substrate categories for hard substrate surveys.

Category	% cover (substrate)	Abundance (taxonomic)
0	Absent	Absent
1	>0 – 10	Rare
2	11 – 30	Uncommon
3	31 – 50	Common
4	51 – 75	Abundant
5	75 – 100	Dominant

Table 5.2 Percentage cover and abundance categories for hard substrate rapid assessment surveys.

Substrate category	Category	Description.
Hard corals.	Acropora	
	Pocillopora	
	Branching – other	All other branching growth forms.
	Massive	Massive corals (except *Porites*).
	Porites	All *Porites* colonies.
	Encrusting	
	Other hard corals	All living hard corals not falling into the above categories.
	Millepora	
	Hard coral - dead	All *in situ* dead hard corals.
	Hard coral - rubble	All displaced or broken fragments of dead hard coral.
Soft corals, gorgonians, etc.	Xeniidae	
	Other soft corals	All other soft corals
	Gorgonians	Gorgonians, sea whips and black coral
Others.	Corallimorpharians	
	Other sessile invertebrates	
	Calcareous algae	
	Turf algae	
	Algal assemblage/mat	Multi-species areas of small algae/mat
	Phaeophytes	Kelps (*Sargassum* spp. etc.)
	Other macroalgae	All other macroalgae

Table 5.3 Taxonomic categories for hard substrate surveys.

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6

REEF FISH

6.1 INTRODUCTION

Fishes are the most conspicuous inhabitants of coral reefs, occurring in schools of up to thousands of individuals and displaying striking colours, shapes and patterns. Fishes not only contribute to the aesthetic value of coral reefs, they also constitute a major component of total biodiversity (BELLWOOD & HUGHES 2001), are a source of economic value (RUSS 1991) and contribute to the overall health and resilience of coral reef ecosystems via a number of ecological processes (BELLWOOD et al. 2003).

About 1,350 species of fishes are known from the Red Sea (GOREN & DOR 1994). Distinct assemblages occur in the Gulf of Suez, the Gulf of Aqaba and the central and northern Red Sea, the southern Red Sea and the Gulf of Aden (SHEPPARD et al. 1992). The level of endemism amongst Red Sea fishes is about 17%. However, as SHEPPARD et al. (1992) point out, this average value has a great range. For example, the degree of endemism amongst small, benthic, territorial groups such as dottybacks (Pseudochromidae) and triple fins (Trypterygiidae) is about 90%, while endemics are almost absent amongst pelagic species.

There are very few accounts of the ichthyofauna of the Gulf of Aden. Al-Sakaff & Essen (1999) listed 195 species of fishes caught in commercial trawlers from the Gulf of Aden and Arabian Sea coastline of Yemen. Kemp (2000) surveyed the ichthyofauna of the Shabwa and Hadramaut provinces of the Republic of Yemen and recorded 267 species, including eight new records. Kemp (1998) surveyed a number of reef-associated fish groups in the Socotra Archipelago. Then, using regional data on chaetodontid fishes, Kemp (1998) distinguished the Arabian representatives into three groups. These are the Red Sea and western Gulf of Aden; Socotra, Oman and the Gulf; and east Africa, the Seychelles and the Maldives. On this basis, the Socotra Archipelago has a regionally high conservation value because its fish fauna appears to be distinctly different from the rest of the Red Sea and Gulf of Aden.

The fishes of the Red Sea and Gulf of Aden have been prominent in the recent scientific history of the region, with many of the early European explorers undertaking ichthyological collections (Vine & Schmid 1987). Artisanal fishing has been socially and economically important for centuries along the coastlines of all countries bordering the Red Sea and Gulf of Aden. Low population densities, traditional management practices and limited commercial demand have helped to keep this activity ecologically sustainable (Gladstone et al. 1999). However, a number of developments threaten this sustainability, such as the use of more modern equipment, the availability of ice, the participation of foreign workers (especially in the Saudi Arabian Red Sea waters), government support, the spread of illegal fishing (especially for shark fins), aquaculture and the rise of recreational fishing in some areas. Such developments have led to the decline of traditional community-based management practices. For example, the practice of cooperatively rotating fishing activities among reefs of the Farasan Islands (Saudi Arabia) shared by a number of villages, was traditionally used as a means of preventing the over-exploitation of fish stocks on shared reefs. However, the practice has broken down in the face of increased fishing pressure from foreign workers who do not understand local customs and have different economic needs (Gladstone 2000). The isolation of the Socotra Archipelago from markets, seasonal weather that limits access to many reefs and a cooperative, traditional management system ensured that catches of fish and sharks were sustainable. However, increasing international demand for shark fins and the high prices paid for dried fins have caused this fishery to become unsustainable (MacAlister Elliott & Partners 1996). In order to support sustainable uses, traditional fisheries management practices will need to be supplemented by alternative approaches, such as the establishment of marine protected areas (MPAs).

There are a number of pressures on the biodiversity and natural systems of the Red Sea and Gulf of Aden arising from the rapid development and widening exploitation of the marine and coastal environments (PERSGA 1998; Wilkinson 2000). These pressures include disturbance to coastal wetlands, clearing and degradation of mangroves, loss of seagrass beds, destruction of coral reefs, unsustainable use of living marine resources (for example, through overfishing and unregulated shark fishing), threats to important species (such as marine turtles, marine mammals and seabirds), marine pollution, poor planning of the coastal zone, discharge of effluents, dredging and filling of coastal habitats, and reduction of freshwater flows to the coastal zone.

A number of management initiatives have been set up in the Red Sea and Gulf of Aden region that will require regular monitoring to assess their effectiveness, including the Red Sea and Gulf of Aden Regional Network of Marine Protected Areas (PERSGA/GEF 2002). Monitoring of natural systems and species of interest will generate feedback to managers on the outcomes of management strategies and provide fundamental information on natural dynamics. The quality of the monitoring information is crucially important for ecologically and socially sustainable management.

Monitoring programmes implemented at the scale of a country or region can be expensive and logistically difficult to implement. The monitoring methods must be time and cost-effective, whilst fulfilling the information needs of managers and being appropriate to the species of interest. Most monitoring programmes for fishes are designed to encompass a number of species. It is therefore important that the methodology and design of the monitoring programme are appropriate for the biology of the species and the scales at which natural fluctuations occur. In particular, the following biological factors are likely to be important considerations in designing surveys: (1) spatial and temporal patterns in the distribution of the species; (2) size and frequency of movements, particularly in relation to the size of sampling units; (3) spatial and temporal scales at which abundance varies. Important methodological considerations include the size and shape of the sampling unit (such as the transect) and the ways in which the units are surveyed. Optimal transect dimensions will be those that, based on the results of pilot studies, reduce variability, increase precision and are logistically feasible to implement. Further design factors that need to be addressed include the number of replicate sampling units and their spatial and temporal deployment (MAPSTONE & AYLING 1998). These considerations will be addressed in the standard survey methods for reef fishes presented below.

Logistical constraints in long-term monitoring programmes mean that sites may only be sampled annually. This could lead to erroneous conclusions about long-term temporal trends if potential sources of variation occurring at the time of sampling (for example, time of day, tidal cycle or season) are not understood and accounted for in the sampling design. For example, THOMPSON & MAPSTONE (2002) found that variation in the abundance of fishes from the families Chaetodontidae, Lethrinidae and Labridae between successive days was as great as, or similar to, the variation in abundance between successive years. This variation makes it difficult to detect changes that may be occurring as a result of human disturbance or management intervention.

A variety of survey methods are used around the world for research, monitoring and survey programmes by scientists, management agencies and community groups. Regional and global assessments of the status of fishes on coral reefs are likely to be limited by the quality of the information collected and the range of methods used. The approach taken in the Red Sea and Gulf of Aden has been to develop standard methods that will allow comparisons and assessments among the countries in the region.

The standard survey methods for fishes presented here will be used to evaluate the status of fish assemblages and individual species of importance in the Red Sea and Gulf of Aden region and to monitor the way both change through time. Monitoring will be carried out in order to understand the scale of natural variations and to evaluate the effectiveness of management.

The methods that will be used here are underwater visual surveys. Forms of this technique are now routinely used to assess fish biodiversity for long-term monitoring and for assessing the effectiveness of management. A considerable amount of research has been undertaken into the methodological aspects of underwater visual surveys for fishes, with the goal of eliminating bias and improving accuracy and precision (THOMPSON & MAPSTONE 1997, 2002). The present chapter provides a review of a number of existing survey methods. These include a method appropriate for use by community dive groups (the Reef Check method), techniques for rapid assessment and also an in-depth analysis of a method suitable for the collection of detailed information on distribution, abundance and length of fishes inhabiting coral reefs. A number of other survey methods are also reviewed and described, which may be suitable for other applications in the Red Sea and Gulf of Aden region.

6.2 METHODOLOGIES

A number of different underwater visual survey methods for reef fishes are illustrated here. They provide for rapid, broad-scale assessments of reef fish status (the Reef Check surveys), detailed information on the population structure of a large number of key species, biodiversity assessments of regional fish faunas and assessments of the impacts of aquarium fish collecting. Choice of method will depend on the reason that information is required, the use to which this information will be put and on technical and logistical capabilities.

6.2.1 Reef Check Surveys

The Reef Check survey methodology is designed to provide a rapid, broad-scale assessment of the distribution and abundance

An analysis of Reef Check data collected in more than 60 countries between 1997 and 2001 has provided a snapshot of the current status of fishes on coral reefs and an indication of trends in the abundance of some key species.

Data collected by Reef Check teams between 1997 and 2001 revealed:

- No spiny lobster were recorded at 83% of reefs surveyed, indicating severe overfishing
- A significant decline in the abundance of butterfly-fish
- No grouper larger than 30 cm were recorded at 48% of reefs surveyed, indicating severe overfishing
- Four species of reef fish are believed to be in ‘critical condition’: Nassau grouper (not recorded from 82% of shallow Caribbean reefs surveyed); Barramundi cod (absent from 95% of Indo-Pacific reefs); bumphead parrotfish (absent from 89% of Indo-Pacific reefs); and humphead wrasse (absent from 88% of Indo-Pacific reefs)
- parrotfish greater than 20 cm in length were not observed on 55% of reefs surveyed
- The Reef Check surveys also revealed substantial differences between regions in the dominant groups of fishes: fish belonging to the families Scaridae and Haemulidae were most abundant on Atlantic reefs, and fish belonging to the families Chaetodontidae and Lutjanidae were most abundant on Indo-Pacific reefs
- Marine protected areas appear to be showing benefits for some species of fishes in developing countries: five of the 10 indicator species are more abundant in marine protected areas than comparable fished areas.

Source: HODGSON & LIEBLER (2002)

Table 6.1 Five years of Reef Check, 1997 to 2001.

of a number of fish species known to be either indicators of reef health (for example chaetodontids) or susceptible to the effects of fishing (for example serranids and scarids). The Reef Check method has been widely adopted by recreational dive groups in more than 60 countries (Hodgson 2000; Hodgson & Liebler 2002), including Egypt, Jordan and Yemen. It is a rapid approach to surveys of reef fishes that can be undertaken with a minimum of training. The Reef Check methodology is included here because of its value in obtaining broad-scale snapshots of the status of reef fish, its potential to provide more frequent surveys of specific sites and because of its role in engaging and educating the wider community. The Reef Check methodology has provided information on the global status of coral reefs and trends in reef status over recent years (see Table 6.1). Survey teams wishing to undertake Reef Check surveys and participate in the programme should contact the Reef Check organisation (listed under Web Pages).

The following description of the Reef Check methodology has been adapted from Reef Check (2003).

Site Selection

Reef Check surveys are undertaken at sites representative of the range of human impact occurring in an area. They should include a site that is pristine or shows few signs of human impact, one experiencing moderate levels of human impact (for example from fishing or pollution) and one that is severely impacted by human usage. The Reef Check team surveys the most pristine site in the area when it is not possible to survey more than one site.

Surveys are performed on the exposed or seaward section of reefs, on reefs that contain reef crest and reef slope habitats. Reef Check surveys use transects that follow a depth contour which runs parallel to the shore or reef face, not perpendicular to the reef face or along a depth gradient. Two depths are surveyed at each site: shallow (2–6 m) and mid-depth (6–12 m), with depth based on lowest low water.

Methodology

Four transects of 20 m are surveyed for each depth and site, with transects laid along the depth contour. The surveys proceed in the following manner:

- Transects are laid using a 100 m fibreglass tape measure with 5 m intervals between replicate 20 m transects.
- One pair of divers lays out the complete 100 m tape measure then swims back along the tape ensuring that it lies clearly along the reef.
- In sites where the reef is not continuous (for example, reef slope areas interspersed with sand or drop-offs) 20 m tape measures are used to mark out the individual 20 m sections of the transect, each separated by at least 5 m.
- The start and end of the transect are marked with floats, and the position of one of the floats is recorded on a chart or with Global Positioning System (GPS). This allows the site to be easily located for subsequent surveys. In addition, the position of the site in relation to prominent landmarks is recorded as a backup in case of loss of GPS data.
- Surveys of fish transects start no earlier than 0900 hours.
- Divers wait for 15 minutes after the transects have been deployed and checked, to allow time for fish that

Common Name	Family or Species
Grouper > 30 cm	Serranidae
Grunts / sweetlips / margates	Haemulidae
Butterfly-fish	Chaetodontidae
Broomtail wrasse	*Cheilinus lunulatus*
Humphead wrasse	*Cheilinus undulatus*
Bumphead parrotfish	*Bolbometopon muricatum*
Parrotfish > 20 cm	Scaridae
Moray eel (any species)	Muraenidae

Table 6.2 Groups of reef fishes recommended for survey in the Red Sea under the Reef Check programme (Reef Check 2003).

may have been disturbed by the divers laying the transect to return to the area.

- Fish are surveyed by one or both divers of the buddy pair. If both divers in the buddy pair are experienced fish observers they alternate in surveying fish along 5 m lengths of the transect.
- The fish observer swims along the transect about 1 m above the tape and records the abundance of all indicator species (Table 6.2) in an area 2.5 m from both sides of the tape measure and up to 5 m above the substratum. When the 5 m distance along the tape measure is reached the observer stops swimming and, while waiting for 3 minutes, records the abundance of all indicator species that come out of hiding. At the end of the 3 minutes the observer begins swimming along the next 5 m section of transect.
- This process is repeated until the end of the 20 m transect is reached. The buddy pair then swims the 5 m along the tape measure to the beginning of the next fish transect (fish are not counted in this 5 m interval).
- The abundance of all indicator species is recorded on a standard data sheet (Appendix 6.7.1).

The abundance of all fish observed is recorded regardless of size, apart from those belonging to two families, the Serranidae (groupers) and the Scaridae (parrotfishes), where only those exceeding 30 cm and 20 cm respectively are recorded (Table 6.2). The lengths of groupers are estimated and recorded on the data sheet in the Comments section. For these reasons fish observers need to be proficient in estimating two distances underwater, the 2.5 m belt on both sides of the tape measure and the minimum lengths of groupers and parrotfishes. Reef Check survey teams carry a 2.5 m pole that is placed on the substrate and observed by divers at the beginning of the dive, so that divers become accustomed to the scale of this distance underwater. In addition, survey teams familiarise themselves with the 20 and 30 cm lengths by carrying a number of sticks of these lengths and familiarising themselves with the appearance of these lengths at the start of each dive.

Site Descriptions

The characteristics of all sites included in the Reef Check survey are described to allow linkages to be made between the status of reefs and the status of the indicator species (see Appendix 6.7.1). The site description is conducted at the same time as the fish surveys by other team members.

6.2.2 Rapid Visual Counts

Rapid visual counts are frequently undertaken in situations where the time and resources available to collect detailed information (such as species level data) are unavailable, where a large number of sites have to be surveyed or when it is desirable to collect information from the same site on a range of biophysical parameters (such as a subset of species and substrate composition). They can be in the form of qualitative or semi-quantitative surveys.

Rapid visual counts are performed by free-swimming divers surveying a search area that has not been determined using transects or tape measures. Divers swim over the reef for a specified period of time recording fish species and their abundance. Rapid visual counts are useful over large sections of coastline for recording reconnaissance-level information or preliminary data prior to more detailed surveys (ORMOND et al. 1984). They are also useful for trained observers for obtaining the same level of information (fish species, abundance, length) as the more labour intensive transect methods. This method has the advantage that a larger area can be covered than would be covered by surveys using belt transects, due to time saved not having to deploy and retrieve the replicate transects. Time intervals used in rapid visual counts are 3 (MEEKAN & CHOAT 1997), 30 (RUSS 1984a,b), 45 (WILLIAMS 1982) and 75 minutes (SYMS 1995). This method is suitable for very mobile and timid species of fishes that may flee from an area while a tape measure is being deployed. A disadvantage of the method is the possibility that variable areas of reef are searched, thereby confounding comparisons. Variation in area searched may arise from variation in underwater visibility, experience of observers and current strength. Unplanned variation may also be introduced by divers crossing habitat boundaries. This technique may therefore be subject to more sources of variation that are not accounted for than more formalised transect surveys.

Rapid visual counts have been used in a number of different applications. To describe patterns in the distribution and abundance of coral reef fishes across different reef types, WILLIAMS (1982) employed 45 minute swim surveys by divers. The surveys were performed on the outer reef slope by divers swimming in a zigzag pattern from the surface to 13 m depth and recording fishes occurring within 5 m either side. Swims covered approximately 150 m of reef front. RUSS (1984a,b) surveyed richness and abundance of herbivorous reef fishes on the Great Barrier Reef using 30 minute swims, during which fishes occurring within 5 m either side of the observer were recorded. The abundance of each species was recorded on a log 3 abundance scale. SYMS (1995) defined the habitat characteristics of blennioid fishes with 75 minute swims during which all occurrences of fishes were recorded and the habitat and micro-habitat occupied by each individual was described.

Different methods of rapid visual counts have been undertaken in the Red Sea and Gulf of Aden. In this region it has often been required to undertake surveys over large distances of coastline to provide information suitable for the development of coastal management strategies. ORMOND et al. (1984) employed a range of different survey techniques including rapid visual counts as part of the process of providing information suitable for development of a coastal zone management plan for the 1800 km Saudi Arabian Red Sea coastline. They surveyed more than 350 sites using a rapid visual count consisting of a 10 minute snorkel swim at each site (usually covering about 100 m of the reef edge) during which the richness and abundance of reef fishes and the abundance of pelagic fishes were recorded in categories (superabundant, abundant, numerous, a bit limited, noticeably few). In addition, the abundance of each species of butterfly-fish, trigger fish and puffer fish was observed for each site.

KEMP & BENZONI (2000) employed a modified form of rapid visual count to describe the fish assemblages of the north-eastern Gulf of Aden. A 250 m transect was used to record the abundance of all pomacanthid and chaetodontid fishes, with fishes occurring no more than 5 m from the transect recorded. After a series of trials survey lengths were estimated by swimming at a speed of 50 m per five minutes. Consistency of area surveyed was maintained by checking the length of the distance swum after every 10 to 12 transects.

KEMP (1998) used a combination of rapid, qualitative assessment and quantitative assessment to describe the assemblages of fishes of the Socotra Island Group. Rapid, qualitative assessments were undertaken for 15 minutes at sites and representatives of chaetodontid, pomacanthid, acanthurid and balistid fishes were recorded. This data was combined with results from quantitative assessments (which consisted of 250 x 10 m transects), to produce species lists and estimates of relative abundance of chaetodontid and pomacanthid species. Results from these surveys provided information on zoogeographic affinities of the fish fauna of the Socotra Island Group.

Finally, SCHMITT et al. (2002) compared outcomes of roving diver surveys and transect-based visual surveys of reef fishes off Hispaniola. Roving diver surveys consisted of divers swimming around a site for periods of 45 to 60 minutes and recording the abundances of all fishes observed on a log abundance scale: single (1); few (2 to 10); many (11 to 100); abundant (more than 100). Comparisons of the two methods revealed that both recorded the most abundant species while the roving diver method recorded a greater number of rare species. When species were observed by both methods they were recorded at the same relative abundances. SCHMITT et al. (2002) recommended a combination of both methods for measuring effects of fishing and protective management.

6.2.3 Stationary Point Counts

Stationary point counts involve divers recording information about fish species and abundance from a fixed position on the reef within a predefined area. The first step is to record all mobile species occurring within the area as the observer descends to the reef. This provides an initial snapshot of the abundance and richness of the highly mobile species present. Upon reaching the substratum the observer searches the predetermined area for a set period of time counting the less mobile, site-attached species. Areas searched can be set during the design phase of the study, for example, 7 m diameter or 3.5 m from the observer positioned in the centre of the area. Alternatively, convenient reference points on the substratum, such as prominent coral heads, can be selected as the observer is descending and all fish occurring within the reference points are counted. The distances between reference points are measured after counting has finished and the actual area surveyed is calculated. In addition, the actual time to be spent counting less mobile species is determined beforehand during pilot studies, and can vary between 7 minutes (SAMOILYS & CARLOS 1992; CONNELL et al. 1998) and 15 minutes (GLADSTONE 1994).

The stationary visual count method has the advantage that it is more rapid to implement than transect surveys involving tape measures and therefore a greater number of replicate counts may be achieved. The method provides the same data as transect counts and is particularly useful for counts of more mobile species that flee readily at the approach of divers. The disadvantages of this method include the variation it may introduce into the behaviour of smaller species of fish and the possibility that, under some circumstances, stationary divers may attract particular species of fish and thereby inflate estimates of their abundance. The technique also relies on a greater distance of underwater visibility (the radius of the circle being counted) than may be required for transect-based counts (KINGSFORD & BATTERSHILL 1998).

SAMOILYS & CARLOS (1992) compared stationary point counts and transect counts and found only minor differences between the two techniques in the accuracy and precision of their estimates of fish density. Stationary point counts were cheaper to carry out because there was no need to deploy and retrieve tape measures. However, stationary point counts are usually done by a single observer and this may limit their effectiveness from the viewpoint of diver safety. GLADSTONE (1994) used stationary point counts of 15 minutes duration in the Farasan Islands to compare fish assemblages in areas heavily and lightly fished by artisanal fishers. In the Solomon Islands CONNELL et al. (1998) used stationary point counts of 7 m radius and 7 minutes duration when testing differences in estimates of fish density between visual surveys and catch effort surveys. HAWKINS et al. (1999) used stationary point counts to test whether density of fishes differed between three sites that were popular with divers and three sites that were part of a reserve where diving was not permitted. Their technique consisted of laying a 10 m tape measure at each point on the reef and counting fishes from the centre of the point up to a radius of 5 m and a height of 5 m above the reef. All fishes occurring within the area, or passing through it, were counted over a 15 minute period.

6.2.4 Video Counts

The behaviour of fishes can be influenced either positively or negatively by the presence of divers, leading to both over- and underestimates of fish species richness and abundance (COLE 1994; KULBICKI 1998; THOMPSON & MAPSTONE 2002). This may potentially lead to erroneous conclusions about natural patterns in distribution and abundance and the impacts of human uses and management. In addition, it may not be possible for divers to undertake underwater visual surveys in some areas and habitats because of concerns for diver safety due to depth and currents. In these circumstances an alternative method would be to deploy a remote, automated, underwater video camera along with bait on the sea floor. The camera would record all fish attracted to the bait for a specified period of time, determined during a pilot study. At the end of the observation period the camera is retrieved and redeployed at different spots in the same location to provide replicate samples. Tapes are observed in the laboratory and the estimate of abundance used is the maximum number of individuals of each species seen in the frame at any time during the observation period.

In a study comparing a marine protected area and a control location, WILLIS et al. (2000) and WILLIS & BABCOCK (2000) compared estimates of fish density and length derived from three alternative survey techniques. These were underwater visual surveys, experimental angling and baited underwater video cameras. The authors found that the outcomes of comparisons depended on the species investigated. Visual surveys were the least reliable method for surveys of the snapper, *Pagrus auratus*, with angling and video providing more reliable estimates of density throughout both locations. Length of *P. auratus* was consistently underestimated by diver-based visual surveys. However, the three methods provided comparable estimates of the density of another species, the blue cod, *Parapercis colias*. WILLIS et al. (2000) concluded that several different techniques may have to be used for environmental assessments of fish assemblages due to the variable responses of the species to the different techniques.

The use of underwater video cameras as a survey tool provides the same data as visual surveys, while also providing a permanent record that can be re-checked by other observers. Video surveys may, in fact, provide data on fish that are normally shy of divers or difficult to observe underwater (such as large serranids). Results of video surveys are independent of observers' diving experience and skill in recording fish abundance. The use of stereo video cameras allows fish length to be estimated (HARVEY & SHORTIS 1998; HARVEY et al. 2001). Use of bait may limit the types of fishes that are likely to be attracted and hence observed. For example, counts of herbivorous fishes may be reduced in comparison to diver-based counts. Disadvantages of this method include the initial high cost of purchasing digital video cameras and underwater housings, the need for regular maintenance of underwater housings, and the risk of leakage. The quality of the recordings may also be influenced by the positioning of equipment and there is a risk of damage to the equipment from sharks attracted to the bait.

6.2.5 Detailed Surveys

Detailed surveys of reef fishes are recommended for obtaining information on the population structure of a large number of reef fish species. This can be used to assess national and regional patterns in the distribution and abundance of reef fish assemblages, changes in fish assemblages over time, the status of key species and the outcomes of management interventions (such as the establishment of a marine protected area). The design of the detailed surveys includes replication at a number of spatial scales, reflecting the spatial variability that is characteristic of reef fishes. They therefore require a greater logistical capability to implement. Detailed surveys require considerable expertise in identification of fish species and it is recommended that all participants undergo a period of training and assessment prior to joining survey teams (see General Considerations in 6.2.8).

Habitat Selection

The composition of reef fish assemblages varies between different reef habitats in response to species' habitat preferences, resource availability and ecological processes such as predation and recruitment (RUSS 1984a,b; WILLIAMS 1991; SWEATMAN 1997). Assessments of reef fish assemblages must therefore include all levels of habitat variability occurring in the survey area. Primary sources of habitat variability for reef fishes in the Red Sea and Gulf of Aden region are the type of reef (such as platform or fringing reef) and the intra-reef habitat (such as reef crest or reef slope). Surveys and monitoring programmes may need to include representatives of all reef types occurring in the survey area. A range of reef types have been described for the Red Sea and Gulf of Aden, not all of which occur throughout the region (Table 6.3). Coastal fringing reefs occur on some parts of the coastline in the southern Red Sea. However, these have been excluded from the list of potential survey sites because they often experience low visibility and are subjected to varying levels of land-based influences. Additional reef types known to occur in the region include small and reticulate patch reefs, coral bommies, coral

Region	Reef types present
Gulf of Aqaba, Straits of Tiran	Coastal fringing reefs Island fringing reefs Platform reefs
Northern-central Red Sea	Coastal fringing reefs Island fringing reefs Platform reefs Barrier reefs Atoll-like reefs
Southern Red Sea	Mid-shelf reefs Island fringing reefs Platform reefs Outer-shelf reefs Atoll-like reefs
Gulf of Aden	Island fringing reefs Platform reefs Coastal fringing reefs
Northern Gulf of Aden coast of Yemen	Coral communities fringing mainland rocky shores Coral communities on hard or soft substrata
Northern Gulf of Aden coast of Somalia	Coral communities fringing mainland rocky shores Coral communities on hard or soft substrata
Socotra Island Group	Coral communities on hard or soft substrata

Table 6.3 Reef types occurring in the Red Sea and Gulf of Aden, based on descriptions in SHEPPARD & SHEPPARD (1991); SHEPPARD et al. (1992); MACALISTER ELLIOTT & PARTNERS (1996); ALI et al. (1997); KEMP (1998); DEVANTIER et al. (2000); KEMP & BENZONI (2000).

pinnacles and coral carpets (SHEPPARD et al. 1992; DE VANTIER et al. 2000). These have not been included in habitats recommended for survey because their small size, patchy distribution and complex physical structure limits the possibility of obtaining sufficient replicate transects of the same length.

At the beginning of a reef survey and monitoring programme, when the programme is being designed, the survey team prepares a list of all reef types that occur in the survey area. This information is obtained from navigation charts, satellite images and from the combined experience of the survey team. For the purposes of statistical analysis, the same numbers of reefs of each reef type are surveyed.

For the purposes of comparability among surveys and for the efficient use of resources, it is recommended that reef fish surveys occur only in the reef slope habitat at a depth of 6 to 9 m. Exceptions to this include surveys for species that predominantly occur in other habitats (for example, some aquarium fish species that occur in reef flat habitats) or surveys designed to quantify habitat-related differences in fish assemblages, where it will be necessary to survey as many habitats as possible. Reef slope habitats do not exist on some reefs in the region, such as the coral communities growing on hard and soft substrata along the Gulf of Aden coast of Yemen (KEMP & BENZONI 2000). In these situations it is recommended that surveys and monitoring in different coral communities occur at a standard depth (for example, 5 m) with transects laid in a consistent direction at the same depth.

Sampling Design

The following sampling design has been based on experience from other regions, in particular the Great Barrier Reef (HALFORD & THOMPSON 1994). Sampling design needs to be based on information on the scales of spatial and temporal change in fish abundance in the areas where the surveys and monitoring will be undertaken. This will provide, for example, estimates of variance between replicate surveys in a habitat and through time.

The following sampling design is recommended:

- All surveys are undertaken in the reef slope habitat at a depth of 6 to 9 m. The reef slope is a common habitat occurring on all reef types and includes a number of representative species. Restriction of sampling to this habitat in all reefs allows meaningful comparisons to be made between reefs and between regions. Sampling at a depth of 6–9 m reduces disturbance to divers from wave surge and allows surveys to be undertaken within the no-decompression limits for safe diving.
- Each reef type is surveyed at three replicate locations. For a continuous fringing reef each location could consist of a homogeneous stretch of reef at least 1 km in length. In the case of platform reefs, each reef would be regarded as a separate location. Replicate locations should be separated by several kilometres.
- Three replicate sites at each location are surveyed. Each site will consist of a homogeneous portion of the location. Surveys of replicate sites within each location will provide information on small-scale differences in fish assemblages that may occur due to small-scale differences in reef topography, reef biogenic composition or recruitment. Replicate sites are separated by approximately 200 m (the distance between the edge of one site where transects finish and the edge of the next where transects commence).
- Five replicate transects in each site are surveyed. Surveys will be undertaken using transects of 50 x 5 m for large mobile fishes and 50 x 1 m for small species. These transect dimensions have been shown to reduce variability and increase the precision of counts of fish density (MAPSTONE & AYLING 1998). Individual replicate transects are placed 5m apart from the end of one transect to the beginning of the next.

Species Selection

The species recommended for survey are listed in Appendix 6.7.2. These species have been divided into those surveyed in 50 x 5 m transects and those surveyed in 50 x 1 m transects. The list includes species that are common throughout the Red Sea and Gulf of Aden, species of particular importance due to their significance for fishing and ornamental fish collecting, species from all trophic groups, and species restricted to particular parts of the Red Sea and Gulf of Aden.

Only individuals of age 1+ are surveyed. The actual size of individual fish of this age will vary between species and locations and so the size to be surveyed is agreed upon prior to the commencement of surveys.

In large-scale survey and monitoring programmes it is not possible to survey all reefs simultaneously, or even within a short period of time. As the survey progresses those reefs sampled later in the programme will have accumulated a greater number of recruits than reefs that were sampled at the beginning of the programme. This will exaggerate the differences between reefs in counts of total fish density. This explains why surveys are restricted to counts of 1+ individuals.

Surveys of Whole Assemblages

Where the objective of surveys is to provide information on patterns in the distribution and composition of whole fish assemblages, all fish observed during transects will be identified and counted. This will require specialist training for observers in fish identification or, alternatively, a separation of duties by experienced observers such that one observer surveys all large, mobile species and the second observer concentrates on smaller, more cryptic species. Considerable training and evaluation of observers is recommended prior to field studies commencing, as discussed in General Considerations in 6.2.8.

Information arising from underwater visual surveys of complete fish biodiversity has been used in understanding important ecological processes, for comparing the conservation value of locations and for assessing community-level outcomes of management strategies. It should be noted, however, that underwater visual surveys have a number of limitations in relation to providing descriptions of whole fish assemblages. Firstly, they underestimate the occurrence and abundance of species that show diver-avoidance behaviour and may overestimate abundance of diver-friendly species (COLE 1994; KULBICKI 1998). Second, they may be inadequate for assessments of reef-associated pelagic, schooling species (THRESHER & GUNN 1986). Third, they underestimate biodiversity, abundance and biomass of cryptic species and therefore, underestimate the contribution made by this group to ecological processes (ACKERMAN & BELLWOOD 2000). When underwater visual surveys are implemented in the same manner across all locations under consideration, they provide information that can be used for comparative purposes. However, additional techniques (such as poisons, anaesthetics and traps) will be required when detailed information on reef fish biodiversity is necessary (WILLIS 2001).

Site Selection

The reefs to be surveyed, and the position of sites within the reefs, are determined prior to the surveys beginning, using information from navigation charts, aerial photographs and the experience of the survey team. In addition, a reconnaissance survey should be undertaken prior to the actual surveys to confirm that it will be possible to obtain the required number of replicate sites within each reef. Positions of reefs and sites within reefs need to be recorded using GPS and stored for future return.

To avoid biases associated with times of day when sites are surveyed, the order in which replicate locations are surveyed is randomly determined on each sampling occasion and the order in which individual sites are surveyed within each location is randomly determined on each survey occasion.

Survey Procedure

Survey teams consist of a minimum of three persons, including two divers and one person acting as a boat attendant and providing diver support. The dive team will consist of one diver who undertakes the fish counts (the observer) and one diver who lays the tape measures (the tape layer). The dive team will require scuba-diving equipment, waterproof notebooks or slates, with pencils and five 50 m fibreglass tape measures.

The survey team returns to the previously selected site to begin the survey. For the purposes of the statistical analyses of survey results it is not necessary for the surveys to commence at exactly the same point on the reef each time.

Upon entering the water the two divers swim to the reef slope and prepare to begin the surveys at the required depth of 6–9 m. Both divers begin swimming along the depth contour. The observer records the fish while swimming along the depth contour at a constant speed, while the tape layer, swimming near to and slightly behind the observer, lays out the tape measure. The observer records the target fish occurring within a belt 5 m to one side and 5 m above the tape layer (a recommended design for data sheets is provided in Appendix 6.7.3). The observer and tape layer swim at the same speed so the tape layer can signal to the observer when the end of the 50 m tape is reached.

It is critical that transects are completed in the same amount of time, to reduce biases in estimates of density and species richness associated with different survey intensities. The time required will depend on a range of factors including the observers' experience in fish identification, the topographic complexity of the site and the actual species richness of the site. The time needed to complete transects should be determined in a series of pilot studies undertaken prior to the commencement of field surveys.

The observer ceases counting fishes when the end of the 50 m tape is reached. At this point the tape layer places the tape measure on the substrate and the observer and tape layer swim a distance of approximately 25 m to begin the next transect. The second and subsequent transects are repeated in the same way until the five transects of 50 x 5 m have been completed.

At the end of the fifth transect the observer turns around and swims back about 1 m above the tape measure, counting the fish seen in a belt 1 m on the opposite side of the tape measure to that on which the 5 m strip was counted (and within 5 m above the tape). The tape layer swims behind the observer and reels in the tape measure. At the end of the 50 m the observer stops counting and the divers swim to the next tape measure. The procedure is repeated until the five 50 x 1 m transects have been completed, at which point the observer and tape layer return to the boat together.

A potential source of bias in assessments of fish density using this technique is variation in the width of the 5 m or 1 m strip, as estimated by the observer. This bias can be reduced or eliminated by training and regular calibration of observers' estimates of distance underwater. At the beginning of each site the tape layer lays out 5 m of tape onto the substratum and the observer positions himself in the middle, allowing himself to recognize a distance of 5 m underwater. The procedure is then repeated for the 1 m distance.

Method of Counting Fish

An important consideration in undertaking underwater visual surveys for fishes is the way in which fish are counted on the transect (HALFORD & THOMPSON 1994). Underwater visual surveys are designed to provide instantaneous estimates of the abundance of each fish species in a transect. However, this is not possible to achieve because of the time taken to swim along the transect and record the data. It is assumed, however, that the total number of fish counted while swimming along the transect represents an instantaneous count of the fish that were present in the entire transect at the beginning of the count. Because of the nature of the method it is important to ensure that large, mobile fish, that may only be present in a transect for a short period of time, are counted and that double-counting of individual fish is avoided.

These potential errors can be eliminated in the technique of counting while swimming along a transect. This can be achieved by the observer progressively observing small segments of the transect immediately in front of him to a distance of approximately 10 m (depending on visibility). On first observation of the segment the observer identifies and counts the large mobile fishes (for example lethrinids, scarids, acanthurids, labrids and serranids), followed by the less mobile species (such as chaetodontids). Mobile fish entering the segment after counting has begun are not included. The observer then searches for and records the numbers of less mobile and more cryptic species occurring in the segment, as well as any mobile species that were obscured and not counted on the first observation. This process is repeated until the observer reaches the end of the transect.

Estimating Abundance Using Abundance Categories

Some fishes occur in very large groups and therefore can present difficulties in enumeration for less experienced observers. Complete counts of large groups of fish will slow progress and may lead to underestimates of the abundance of other species. An alternative to complete counts is the use of abundance categories, where the estimated number of fish in a group is scored according to logarithmic abundance categories (Table 6.4). Abundance categories are particularly useful when surveying numerically dominant species such as schooling serranids, pomacentrids, acanthurids and scarids. Graphical presentation of the survey results using abundance categories is done by use of the lowest numerical value for the abundance category. Analysis of abundance category data has been undertaken in two ways. Firstly, prior to statistical analysis, abundance scores are converted back to abundances by using the mid-point of the abundance category. For example, an abundance score in the 4 category is converted to an estimated abundance of 19 fishes. In cases where scores in the highest categories are recorded, the minimum value of the abundance category is used, for instance, 244 (ENGLISH et al. 1997). RUSS (1984a,b) used actual abundance categories in analysis of variance because it is equivalent to using log-transformed actual counts.

Log 3 Abundance Category	Number of Fishes
1	1
2	2-3
3	4-9
4	10-27
5	28-81
6	82-243
7	244-729

Table 6.4 Numbers of fishes within abundance categories based on a log 3 abundance scale (after RUSS 1984a,b).

6.2.6 Aquarium Fish Collecting

Coral reef fishes have been commercially collected for sale as ornamental fish for aquaria since the 1930s. The industry has grown considerably since the 1970s, with 45 countries currently supplying fishes. The total global catch of ornamental fishes is small (between 14 and 30 million fish per annum) in comparison with catches of food fishes. Aquarium fish can potentially play an important role in increasing the general community's awareness of coral reef biodiversity. However, their capture raises a number of conservation concerns relating to the nature of collection activities, lack of management, the ecology of the target species and other impacts on coral reef ecosystems (WOOD 2001).

Destructive fishing practices, such as coral breakage to obtain cryptic species and the use of cyanide, can be very damaging to coral reefs. Beyond the collecting activities there may also be high mortality of fishes during handling and transport, especially for species with lower natural longevities (EDWARDS 2002). Although licensing systems have been put in place in many countries in an effort to manage the collection of ornamental fishes, the lack of compliance monitoring and independent field surveys limits the effectiveness of these management initiatives (WOOD 2001). Many of the ornamental fishes targeted by collectors naturally occur at low densities and may also have a lower relative reproductive output, putting them at greater risk of unsustainable exploitation. In addition, there are regional conservation issues relating to the collection of regional endemics. The collection of ornamental fishes may represent an additional disturbance to coral reefs which could already be impacted by overfishing, pollution and coral bleaching (WOOD 2001).

Collecting of ornamental fishes currently occurs in three countries in the Red Sea and Gulf of Aden: Egypt, Saudi Arabia and Yemen (WOOD 2001). In 2000 the activities in each country were directed primarily towards the export market and the size of the industry in each country was regarded as 'small' with up to 50,000 fish exported annually, representing an export value less than US$100,000 (WOOD 2001). There are considerable differences between countries in the number of species collected for the ornamental fish trade. In Egypt 50 species are collected and in Saudi Arabia 117 species are collected. EDWARDS (2002) listed 144 species that were utilised by the aquarium fish trade in the Red Sea and Gulf of Aden and recommended monitoring of 40 key species (Appendix 6.7.4).

Survey Design and Monitoring Methodology

The 40 species recommended for monitoring by EDWARDS (2002) include endemics, rare species, species that are easy to identify and species in high demand in the aquarium fish trade. The list also includes species occupying different reef habitats. For example, *Rhinecanthus assasi* (Picasso trigger fish) occur as solitary individuals and are most abundant on reef flats. *Acanthurus sohal* (sohal surgeon fish) occur in highest densities on reef crests. *Paracirrhites forsteri* (Forster's hawkfish) and *Pseudochromis fridmani* (Fridman's dottyback) are uncommon, cryptic species occurring on reef slopes. *Pseudanthias squamipinnis* (lyretail anthias) is an abundant, schooling species on reef slopes. Surveys and monitoring programmes undertaken to assess the status of populations of ornamental fish and to assess the impacts of collecting need to address these ecological differences in the survey design and methodology. Survey design also needs to be appropriate to the nature of the collecting activities, including the number and types of reefs at which collecting occurs and the geographic spread of these reefs.

Collecting for ornamental fish usually occurs over an entire reef, rather than in specific sites within reefs. Surveys and monitoring programmes need to occur over the same spatial scale as the collecting activities. Where collecting is occurring at several reefs in an area, surveys will need to be performed at a comparable number of control reefs, in addition to the collected reefs. Control reefs need to be selected to be similar to the collected reefs in habitat availability, coral assemblages, and exposure. If collecting is occurring at three mid-shelf platform reefs then monitoring will also need to be undertaken at three comparable mid-shelf reefs where no collecting occurs. When collecting is only occurring at one reef in an area, it is recommended that three comparable control reefs be selected for monitoring. These two scenarios (monitoring multiple collected and multiple control reefs; and monitoring one collected reef and several control reefs) will require different statistical approaches and these are explained in the Data Analysis section. Where reefs are of a sufficient size, surveys and monitoring should occur at replicate sites within each reef, in order to account for possible smaller-scale variation in numbers of reef fish. It is recommended that three sites be surveyed in each reef.

Surveys are undertaken in the reef flat, reef crest and reef slope habitats to account for the range of habitat requirements of the target species. Edwards (2002) further recommended that surveys be undertaken at two depths in the reef slope habitat: 5 to 6 m and 10 to 12 m. Surveys are undertaken in the same habitats at the same depths at control reefs. Where reefs lack this range of habitats (such as large patch reefs occurring over a uniform depth), surveys occur at a fixed depth over areas of uniform coral assemblage and structure and the same areas are surveyed in comparable control reefs.

Fishes are surveyed using two transect dimensions: 5 x 100 m transects (as recommended by EDWARDS 2002) and 1 x 100 m. Two transect dimensions are required so that counts of larger, more mobile species are separated from counts of smaller, more cryptic species. The list of species recommended for monitoring includes large and/or mobile species (such as *Acanthurus sohal*, *Naso lituratus*, *Novaculichthys taeniourus*) and small and/or cryptic species (such as *Paracirrhites forsteri*, *Pseudochromis fridmani*, *Ostracion cubicus*, *Pterois* spp.). Studies have shown that the accuracy of density estimates for each group of fishes improves when counted separately (LINCOLN SMITH 1989).

A minimum of three replicates of each transect need to be performed for each habitat and depth at each site. Individual transects are surveyed in the same manner as those for the detailed surveys and monitoring. Two divers are required, a tape layer and a fish observer. The fish observer records the abundance and length of target species occurring in a 5 m strip on one side of the tape measure. Counting finishes at the end of the 100 m transect and the next replicate transect begins 10 to 20 m away from the end of the first transect. After three 5 x 100 m transects have been surveyed the fish observer turns and swims back along the tape measure recording target species occurring in a 1 m strip to the other side of the tape measure. The number of individuals of naturally abundant species, such as schooling species (for example *Pseudanthias squamipinnis*), is recorded in abundance categories (see Detailed Surveys). This will reduce errors in estimation and the time taken to complete the surveys.

Some of the species recommended for monitoring occur naturally at low densities (such as *Balistoides viridescens*, *Cheilinus* *lunulatus*, *Gomphosus caeruleus*, *Ostracion cubicus*, *Pomacanthus imperator*, *Pomacanthus maculosus*, *Pygoplites diacanthus*, *Arothron diadematus*) or they occur with a patchy distribution (such as *Labroides dimidiatus*, *Amphiprion bicinctus*). It is possible that estimates of the abundance of these species will be highly variable, making it difficult to detect differences (when they do occur) between collected and control reefs. This variability can be reduced by increasing the number of replicate transects, for example from three to five per site. Detailed pilot studies will provide information on the magnitude of variability in abundance for each of the recommended species and also a basis for designing an appropriate field survey programme. The recommendation of three transects is thus a minimum survey effort and should be tested through pilot studies and a power analysis (see section 6.5 on Decision Making).

6.2.7 Surveys of Pelagic Fishes

It is recognised that one of the limitations of underwater visual surveys is their unsuitability for surveys of highly mobile species that are not permanent residents of reefs, such as pelagic fishes (including members of the families Carangidae and Scombridae). Although they may be recorded during standard visual surveys, estimates are likely to be highly variable because these fish may only be seen opportunistically as divers are normally observing the reef substratum during visual surveys.

THRESHER & GUNN (1986) compared estimates of abundance of carangids derived from a number of visual survey techniques. They found that point-based counts gave the most consistent descriptions of the range of abundances for all carangid species, compared with transect-based counts. Within the point-based counts, THRESHER & GUNN (1986) found that instantaneous area counts gave the most precise estimates of abundance. This technique involves a diver swimming along a reef and stopping at 60 second intervals to scan an area 15 m on either side (and from reef to surface) for 5 to 10 seconds. Surveys such as these can be incorporated within detailed surveys.

6.2.8 General considerations

There are some general considerations which need to be taken into account.

Timing of Surveys

Fish activity patterns vary diurnally, seasonally (for example, in association with spawning) and with tidal state (THOMPSON & MAPSTONE 2002). Such variations in activity are likely to lead to variations in the visibility of fishes to divers. Unless accounted for in the design of sampling, variations in activity are a potential, additional source of variation in estimates of fish density and species richness. In addition, due to differences in the times of sunrise and sunset throughout the year, patterns of light availability underwater will change during the year and this is also likely to affect the visibility of fishes to divers. In order to minimize these potential sources of bias it is recommended that sampling occurs between 0830 and 1630 hrs in warmer months and between 0900 and 1600 hrs in cooler months.

In other regions the magnitude of bias associated with tidal state is known to be significant (THOMPSON & MAPSTONE 2002). However, in the Red Sea and Gulf of Aden region it is unknown. The difficulty is due to the absence of daily tides in some parts of the region and the presence of tides of small magnitude that occur in variable cycles in other parts of the region (SHEPPARD et al. 1992). It is therefore recommended that, where significant tidal regimes occur (such as the Gulf of Aqaba, Gulf of Suez and southern Red Sea), locations are sampled over an entire tidal cycle rather than on either a falling or rising tide. Although this may increase the magnitude of differences between sites within locations, it will eliminate tidal state as a potential source of variability between locations.

Quality Control

In addition to environmentally-induced sources of variation known to affect fish counts (such as time of day, season and habitat variability), inter-observer variability is a potential source of variation that needs to be minimised when surveys and monitoring of the same locations are done by a number of different observers. Assessment and monitoring of fishes in the Red Sea and Gulf of Aden region will be performed by different survey teams in each country and it is likely that the composition of the teams will change over time. Quality control in data collection will be critical in ensuring the comparability of information throughout the region and its consistency through time. Individual observers have been shown to differ in their ability to assess fish length (BELL et al. 1985), species composition and abundance (ST JOHN et al. 1990; THOMPSON & MAPSTONE 1997).

The effects of inter-observer variability can be minimised by regular, repeated programmes of training and quality control in the following areas.

Species Identification

The species recommended for survey in the Red Sea and Gulf of Aden region are listed in Appendix 6.7.2. In order for observers to undertake accurate surveys they need to be able to identify each of these species. This can be achieved by survey team members initially familiarising themselves with the appearance of each species using photographic identification guides and being tested by experienced observers. This should be followed by practice surveys in which an experienced observer accompanies a trainee underwater and asks him to identify a range of species. It will be necessary to include all life stages for some species, because appearance is known to change dramatically throughout an individual's life history, for example, following a sex change. A number of practice sessions may be needed until all species have been observed in the field and correctly identified.

Annual evaluation of skills in species identification will be required for all members of a survey team.

Field Surveys

As described in previous sections, the fish surveys need to be carried out in a specified manner in order to reduce the variability between transects. New observers need to be trained, and experienced observers evaluated annually in the fish standard survey methods. Training of new observers will be done by experienced observers and will cover the following:

Deployment of the transect. New observers need to be trained to lay out tape measures in the appropriate habitat along the depth contour, to swim near to and slightly behind the observer and to effectively signal the observer at the end of each transect.

Fish counts. The trainee and an experienced observer (trainer) swim abreast along the tape of a previously laid set of five 50 x 5 m transects. No data is recorded in the first training session. The observer simply points out all individuals of the target species to the trainee. Training is then repeated at another site or on the subsequent day (when disturbance to the fish is less) and the trainee undertakes fish counts. Swimming along the transects in the same manner as the previous day, each person records the fish observed, their abundance and their length (if the person is being trained in the detailed survey methodology). At the end of the transect the team swims to the next transect and repeats the process until five 50 x 5 m transects have been completed. The survey team then return along the transect, counting fish in the 50 x 1 m strip. For these narrower transects the team swims in a line along the transect, with the second person 10 m behind the lead swimmer. The experienced observer and the trainee take turns in swimming order. At the end of the five 50 x 1 m transects the survey team returns to the boat to compare results. This will be done by a paired *t*-test, in which the trainee's results are compared with the trainer's results. Training continues until the difference between the results of the experienced observer and the trainee are non-significant. Importantly, trainees need to be comparable to the experienced observer by the end of the training sessions in both species identification and counts. The experienced observer may need to point out particular species that the trainee has not observed (such as the smaller, cryptic species).

Distance estimation. A critical part of the fish standard survey methods requires divers to estimate distances of 5 m and 1 m from the tape measure, to ensure consistency in the area sampled. At the beginning of the training session the experienced observer lays out a tape measure for a distance of 5 m on the substrate to allow the trainee to acquaint himself with this distance underwater. The observer then asks the trainee to point out a number of features (such as coral heads) that the trainee perceives to be 5 m distant. The observer records the actual distance and indicates to the trainee whether he is accurate, over or underestimating. The training continues until the trainee is accurate in his estimates of the 5 m distance. The same process is then repeated for the 1 m distance.

Fish length estimation. Trainees will require skills in estimating fish length underwater if the detailed survey techniques are being used for either status assessment or monitoring. Data on fish length provides managers and scientists with information that is useful for understanding natural differences in population demographics between areas. The information is also useful for evaluating the impacts of extractive activities (such as fishing) and for assessing the outcomes of management strategies designed to allow recovery of fish stocks after exploitation. The significance of this sort of information means that it is necessary for observers to be trained thoroughly in estimating fish length.

Training in estimating fish length requires 50 plastic model fish that have been cut to various lengths covering the size range of species to be surveyed. Although simple objects of varying length can be used in place of fish models, studies have shown that divers learn this skill more quickly when taught with realistic models (BELL et al. 1985). A sample of fish lengths suitable for this training is shown in Appendix 6.7.5. Each model fish is individually numbered with a random number. Model fish should not be numbered so that the smallest fish is number 1 and the largest fish is number 50. These numbers, and the corresponding length of the model fish, are recorded on a separate sheet of waterproof paper. The model fish are laid out in a random order in a line on the substrate or the bottom of a swimming pool with their numbers visible.

Trainees start by swimming along the line with the information sheet, comparing the actual fish lengths to the appearance of those lengths. Trainees repeat the process by swimming back along the line in the opposite direction, again comparing each model fish's actual length to its appearance. Trainees then return the waterproof sheet of fish lengths to the trainer and undertake a trial by swimming back along the line attempting to estimate the length of each model fish to the nearest centimetre.

After the trial, trainees compare their estimated length to the actual length of each model fish and test the significance of the differences by a paired *t*-test (an example of this is shown in Appendix 6.7.5). Trainers inform trainees about any trends that may be apparent in their estimations, such as whether the trainee is consistently over- or under-estimating the model lengths. Training continues until the result of the *t*-test is non-significant.

Annual assessment. All observers need to undertake annual training, in order to maintain the consistency of data collection across the entire survey team.

In situations where assessment and monitoring are conducted over long periods of time or over considerable distances, there will be a need for multiple observers. It is likely that observers will leave and be replaced by others who may be less experienced. BELL et al. (1985) found that observers generally took six trials of estimating the lengths of model fish for their estimates to be sufficiently accurate. There were, however, differences between individual observers in their rates of learning. BELL et al. (1985) also found that observers lost this ability after 6 months but quickly regained it following another period of training. The authors provided evidence that observers learn more quickly when trained with realistic models of fish compared to training based on lengths of plastic rod. THOMPSON & MAPSTONE (1997) found that training of observers reduced imprecision and bias. However, even after thorough training, individual observer-related bias was still evident for some fish taxa and some individual observers.

6.3 DATA ANALYSIS

Surveys and monitoring of reef fishes are performed for several reasons. They can improve understanding of the distribution and abundance of fish assemblages together with the underlying ecological processes, provide information for decision making as part of management and conservation activities and help to assess the impacts of human activities, including management. The key consideration in collecting information for management purposes is its use in the decision-making process. For example, are fish assemblages uniform throughout the Red Sea and Gulf of Aden? have fish populations increased following the establishment of the marine reserve? have fish populations declined since aquarium fish collecting began? For these and other questions to be confidently answered the data acquired must be tested against an alternative scenario. The most powerful means of doing so is the hypothesis-testing approach with the use of statistics as a means of testing various alternative hypotheses (UNDERWOOD 1997).

A large number of statistical analyses are available by which hypotheses about patterns in data can be tested. Most analyses make specific assumptions about the nature of the data to be analysed, such as the independence of samples, normal distribution of data and homogeneity of variances (SOKAL & ROHLF 1995). Although alternative analyses are possible when these assumptions are not met, they usually provide a less powerful test of the data. The power of a statistical test to detect differences between two sets of data is also affected by characteristics of the data itself. For instance, it will be more difficult for a test to determine that two means are significantly different when the means have a high variance. However, such features of the data may reflect the reality of the population that was sampled. For example, mean values with a high variance may reflect a population in which individuals are abundant but patchily distributed. This distribution pattern often occurs in schooling planktivorous fishes (such as *Pseudanthias squamipinnis)* that inhabit specific coral patches. Highly variable data may also be a function of the way in which the data was collected, for example the size and number of replicate transects. It is therefore critical that, for the purposes of data analysis, considerable effort is devoted during a pilot study to the way in which the data will be collected (ANDREW & MAPSTONE 1987).

6.3.1 Preparation for Data Analysis

Before data collection begins pilot studies are undertaken to answer questions relating to the way in which data are to be collected, such as the type of sampling unit (quadrat, belt transect, for example) and the dimensions of the sampling unit. Pilot studies are also performed to determine the optimal sampling design, which is the way in which the sampling units are to be deployed. This will involve decisions about the number of replicate sampling units and how they are deployed in space and time. There are a number of excellent reviews of this topic and the steps involved in undertaking pilot studies (GREEN 1979; UNDERWOOD 1981; ANDREW & MAPSTONE 1987; UNDERWOOD 1997; KINGSFORD & BATTERSHILL 1998). The following material is synthesised from these sources and only the main points and issues specific to studies of reef fishes will be covered here.

Collection of background information on the species to be surveyed will provide insights into their likely distribution, patterns of abundance, habitat requirements, scale of movements and activity patterns. Such information helps in decisions about the type of sampling unit, the range of dimensions to be tested during a pilot study and the timing of the study.

Preliminary sampling during a pilot study will provide information on the sample unit size and the level of replication that gives the most precise estimate of the mean. Precision is defined as the standard error divided by the mean (ANDREW & MAPSTONE 1987). Data collected during a pilot study should be analysed for each species separately. Precision may decline in sample units that are too large and therefore difficult to count. A number of formulae are useful for determining numbers of replicate samples required to estimate abundance or species richness and these require some information on average density and variance (GREEN 1979; SNEDECOR & COCHRAN 1980; ANDREW & MAPSTONE 1987). These procedures have been used in a number of studies of reef fishes (SALE & SHARP 1983; ST JOHN et al. 1990; MAPSTONE & AYLING 1998). Compromises in type and size of sample unit will have to be made where surveys and monitoring programmes consider many species, where each species is likely to have different scales and ranges of movement, different activity patterns and be distributed in different degrees of patchiness.

Cost-benefit analyses are useful when making decisions about sampling effort when logistical and economic constraints are a factor. Information is needed on the times required for sampling units of different sizes and on increasing numbers of replicates of each sample unit size. Equally important are the considerations of travel time to locations and the costs of field surveys (ANDREW & MAPSTONE 1987; UNDERWOOD 1997). Furthermore, pilot studies provide an opportunity for any logistical difficulties to be sorted out before the main surveys are conducted.

Power analyses are used as part of pilot studies to determine optimal sampling effort, such that a significant difference can be detected for a given effect size. For example, power analyses could determine the optimal number of transects required to detect a 25% difference in density, when it does exist, between two reefs (UNDERWOOD 1981; KEOUGH & MAPSTONE 1995; UNDERWOOD 1997). Power analysis is discussed in more detail in the following section on decision making strategies.

6.3.2 Sampling Design

The sampling design of a survey or monitoring programme relates to the way in which the sample units are deployed in space and time. The sampling design depends on the nature of the investigation, for instance, the hypothesis being tested. The sampling design required to test a hypothesis about the composition of fish assemblages throughout the Red Sea and Gulf of Aden will differ from that required to test a hypothesis about the effects of establishment of a no-take marine reserve. The two sampling designs may differ in the species selected for survey, the spatial scale (local or regional) and the temporal scale (a single survey performed at a particular time or repeated surveys over a five year period, for example). This section will cover sampling designs and the relevant statistical analyses useful for a number of scenarios. Detailed and excellent reviews of the development of appropriate sampling designs are available (WINER 1971; GREEN 1979; HURLBERT 1984; UNDERWOOD 1997; QUINN & KEOUGH 2002) and only the relevant principles will be summarised here.

Studies undertaken to test whether an effect has occurred (such as a change in fish density following establishment of a no-take marine reserve or a change in fish density on reefs on which aquarium fish collecting is permitted) require control locations for comparison. Differences in the naturally occurring temporal dynamics of populations between locations, means that multiple control locations will be needed (UNDERWOOD 1992, 1993). Generalisations regarding patterns and processes will be possible when there is replication at each level of the sampling design, for instance at the level of sample units, sites within locations, locations, reef types, areas along the coastline and times. Nested, or hierarchical, sampling designs are powerful designs for investigating patterns over various temporal and spatial scales (UNDERWOOD 1997).

Numbers of reef fish in an area vary over a range of temporal scales. They vary over a tidal cycle, between different times of the day, between days, between seasons and between years. The significance of such variation differs between species (THOMPSON & MAPSTONE 2002). Depending on the species under investigation and the aim of the study, it may be necessary to replicate sampling over a number of temporal scales. For example, a broad-scale monitoring programme undertaken to assess the status of reef fish populations at a large number of locations may only need to be undertaken annually. However, a survey designed to test the effects of establishment of a marine reserve may need to be undertaken several times to be confident that the differences between the reserve and control locations are not an outcome of natural short-term variations in fish density (KINGSFORD & BATTERSHILL 1998).

Sampling designs and the proposed method of statistical analysis should be discussed with a statistician at the beginning of a study. Decisions at the beginning of the study about the statistical analysis required to test the hypothesis will reveal any potential gaps in the sampling design and verify the method of sample collection. Most statistical analyses require that samples are collected independently and randomly (WINER 1971; UNDERWOOD 1981; SOKAL & ROHLF 1995). Use of random sampling (such as random selection of replicate transects, replicate sites, and replicate times) will allow results to be generalised. Different analytical techniques will be required in situations where fixed sample units are repeatedly sampled over a period of time, such as repeated measures (WINER 1971; QUINN & KEOUGH 2002).

Sampling designs with few degrees of freedom will require a very large difference in the abundance of fishes for a significant difference to be detected. Consider, for example, a sampling design based on analysis of variance (ANOVA) that is used to test for differences in fish density between a single reef where aquarium fish collecting is permitted and a number of control locations. If only three or fewer control locations are used the test will only be able to detect very large differences (due to the relative distribution of F–values for 1 and 3 degrees of freedom). The sampling design will be more powerful if a greater number of control locations are used and this can be simulated during a pilot study.

The following sections provide examples of some forms of data analysis useful for interpreting the results of surveys undertaken for two goals. The first is to describe patterns in the distribution and abundance of populations and assemblages of reef fishes. The second is to assess the impacts of human activities (including management) on reef fishes. It is assumed that readers are familiar with the basics of statistics, the development of hypotheses and the design of surveys to test these hypotheses. Relevant background reading can be found in WINER (1971); GREEN (1979); UNDERWOOD (1981); HURLBERT (1984); UNDERWOOD (1992, 1993, 1997) and QUINN & KEOUGH (2002).

Sampling Designs and Data Analysis for Describing Spatial and Temporal Patterns

A major goal of assessment and monitoring programmes is to describe patterns in the distribution and abundance of organisms and how these change through time. An additional goal of monitoring is to assess the impacts of human activities (covered in the following section). A number of general categories of sampling designs and their associated data analyses are useful for describing natural patterns of spatial and temporal variability, and these will be described in this section. The form of the general sampling design is provided together with an example of data analysis by analysis of variance and its interpretation. Readers interested in more detailed descriptions of the underlying statistical methods should consult relevant texts (GREEN 1979; UNDERWOOD 1981, 1997; KINGSFORD & BATTERSHILL 1998; QUINN & KEOUGH 2002). The following designs are summarised from KINGSFORD & BATTERSHILL (1998) and supported by examples from the primary literature.

Orthogonal sampling designs are useful in situations where it is necessary to evaluate the effects of two or more factors (such as depth and location) on a variable (for example species richness). The sampling design is orthogonal because each level of one factor occurs together with each level of the other factor, for example, where all depths are sampled at each location. The interaction terms provide an assessment of the combined effects of the factors (UNDERWOOD 1981). The orthogonal sampling design provides a test of the null hypothesis that abundance of fishes does not vary between three depth strata on reefs (shallow, medium, deep) and that the pattern is consistent across a number of locations (Table 6.5). A larger number of locations sampled will allow the result to be generalised and provide a more powerful test of the depth factor.

A significant Depth x Location interaction would indicate that the effects of depth are not independent of location. This could mean that fish were more abundant at shallow depths at location 1 and more abundant at medium depths at location 2. UNDERWOOD (1981) recommends that, where significant interactions occur, no statements should be made about significant results for main effects. For example, if a significant result occurred in the present example for Depth x Location and Depth, only the result for the interaction term should be reported. Multiple comparison tests (such as Student-Newman-Keuls or Ryan's test) are used to compare levels when significant results for main effects or interactions occur (UNDERWOOD 1981).

Nested Sampling Designs. The abundance of fishes varies temporally and spatially at both small and large scales. Spatial variation occurs at scales of metres (due to differences in microhabitat), among habitats, among depths, between reefs and between shelf positions. Temporal variation may occur over a period of hours (for example, between morning and midday or between high and low tide), between days (for example, due to differences in lunar phase), between seasons, between years and over decades. It is important to understand the possible existence of variation at these different scales and to have appropriate sampling designs to account for them.

Nested sampling designs allow multiple scales in a source of variation to be tested at the same time (UNDERWOOD 1981, 1997). For example, they allow tests of difference in abundance at the scale of tens of metres and tests of differences at the scale of kilometres, by using replicate sites nested in replicate locations. These sampling designs are also called hierarchical sampling designs. An example of a nested sampling design is shown in Table 6.6. The test examined the null hypothesis that density of fishes was similar at three spatial scales. These were between sites within locations, between locations on the same island and between neighbouring islands. Sites were separated by hundreds of metres, locations on the same island were 5–10 km apart and islands were tens of kilometres apart. All factors in a nested sampling design are treated as random factors (UNDERWOOD 1981).

The nested sampling design illustrated in Table 6.6 produced a significant result for the factor island and non-significant results for the factors location (island) and site (location (island)). The result indicates that fish density

Source of variation	Fixed (F), Random (R)	df	MS denominator
Depth	F	a-1	Depth x Location
Location	R	(b-1)	Residual
Depth x Location		(a-1)(b-1)	Residual
Residual		ab(n-1)	

Table 6.5 An orthogonal sampling design for a survey designed to test the effect of depth on fish abundance (based on an example in KINGSFORD & BATTERSHILL, 1998). 'Depth' is regarded as a fixed factor because all depth strata were sampled; 'Location' is a random factor because a random selection of locations was chosen for survey from amongst a large number of potential locations. There are 'a' levels of the 'Depth' treatment and 'b' levels of the 'Location' treatment; df = degrees of freedom; MS denominator = mean squares used in the denominator of the F-ratio in the ANOVA.

Source of variation	Fixed (F), Random (R)	df	MS denominator
Island	R	a-1	Location (Island)
Location (Island)	R	a(b-1)	Site (Location (Island))
Site (Location (Island))		ab(c-1)	Residual
Residual		abc(n-1)	

Table 6.6 An example of a nested sampling design used to test the null hypothesis that density of fishes does not vary between sites, locations and islands (from KINGSFORD & BATTERSHILL 1998). There are 'a' levels of the Island factor, 'b' levels of the factor Location nested within Island i.e. Location (Island), and 'c' levels of the Site factor nested within Location (Island).

varied significantly between islands but did not differ between locations within islands or between sites within locations on each island. *Post hoc* multiple comparisons of means would not be undertaken in this case to determine which islands differed because the particular islands chosen were a random sample from a large number of potentially similar islands (UNDERWOOD 1981).

RUSS (1984a) used a nested sampling design to test for differences between reefs in the species richness and abundance of herbivorous reef fishes occurring at inshore, mid-shelf and outer-shelf positions on the continental shelf. His results showed that the species richness and total abundance of acanthurids (surgeon fishes) increased from inshore to mid-shelf to outer-shelf reefs. In contrast, there was no significant difference in the species richness and abundance of siganids (rabbit-fishes) between the three shelf positions.

Partially hierarchical sampling designs consist of a mix of orthogonal and nested factors. These designs are useful for testing hypotheses about the single and combined effects of more than one source of variation on a variable. They may be used, for example, to test an hypothesis that abundance of fishes differs between zones on reefs (a fixed, orthogonal factor). They can further test whether such differences are consistent between sites within a reef (a random, nested factor), between reefs (a random factor) and through time (a random, orthogonal factor) (see Table 6.7).

A partially hierarchical sampling design was used by RUSS (1984b) to investigate the scale of spatial variation in species richness and abundance of herbivorous coral reef fishes on the Great Barrier Reef (Table 6.7). He surveyed three reefs occurring in each of two positions on the continental shelf (mid-shelf and outer-shelf) and five reef zones within each reef. Four replicate transects were used to record richness and abundance of representatives of the families Acanthuridae, Scaridae and Siganidae on each reef. For acanthurids and scarids he found that there were significant Reef (Location) x Zone interactions in species richness. The significant interaction indicated that patterns of differences between zones varied between reefs at the same shelf location. For example, species richness of scarids in reef slope, reef crest and back reef zones was greater than richness in reef flat zone at Rib Reef (a mid-shelf reef). However, at John Brewer Reef (another mid-shelf reef) species richness in reef crest, lagoon and back reef zones was greater than in reef slope and reef flat zones. These results indicate that it is not possible to

Source of variation	Fixed (F), Random (R), Nested (N)	df	MS denominator
Location	F	a-1	Reef (Location)
Reef (Location)	R, N	a(b-1)	Residual
Zone	F	c-1	Reef (Location) x Zone
Location x Zone		(a-1)(c-1)	Reef (Location) x Zone
Reef (Location) x Zone		a(b-1)(c-1)	Residual
Residual		abc(n-1)	

Summary of results from RUSS (1984b) illustrating the use of a partially hierarchical sampling design.

Source of variation	Number of species		
	Acanthuridae	Scaridae	Siganidae
Location	**	NS	*
Reef (Location)	NS	***	**
Zone	***	***	***
Location x Zone	NS	NS	NS
Reef (Location) x Zone	**	***	NS
Residual			

NS - $p>0.05$; * - $p<0.05$; ** - $p<0.01$; *** - $p<0.001$

Table 6.7 Partially hierarchical sampling design used by RUSS (1984b) to test a hypothesis about the effect of position of reef on shelf, reef and reef zone on abundance and species richness for three families of herbivorous fishes on the Great Barrier Reef. 'Location' is treated as a fixed, orthogonal factor because both levels of Location (mid-shelf, outer-shelf) were tested; 'Reefs' is treated as a random factor nested in Location; and Zone is treated as a fixed, orthogonal factor because all levels of Zone (reef slope, reef crest, reef flat, lagoon, back reef) were tested. There are 'a' levels of Location, 'b' levels of Reefs and 'c' levels of Zone, df = degrees of freedom and MSdenominator = mean squares used in the denominator of the F-ratio in the ANOVA.

make generalised statements about differences in distribution of species richness between reef zones (RUSS 1984b).

Partially hierarchical sampling designs have a number of interaction terms, such as the Reef (Location) x Zone interaction term in the sampling design of RUSS (1984b). Where significant interaction terms occur, UNDERWOOD (1997) advises that it is not possible to make any statements about the significance of main effects (such as Location), because they are not independent of the results of other terms in the test.

Impact Assessment

The following is designed to expose some means of analysing data collected during surveys to assess the potential impacts of a human activity, such as aquarium fish collecting or declaration of a no-take marine reserve. The examples provided here and the additional references suggested, will allow readers to analyse other possible scenarios.

After-Control-Impact Design (ACI)

Such designs are useful when the effects of a pre-existing disturbance need to be assessed. One example of this would be a programme designed to assess the impacts of

Source of variation	Fixed (F), Random (R), Nested (N)	df	MS denominator
Treatment	F	a-1	Reefs (Treatment)
Reefs (Treatment)	R, N	a(b-1)	Residual
Residual	R	ab(n-1)	

Summary of results of ANOVA.

Source of variation	df	MS	*F*-ratio	*P*
Treatment	1	572.03	418.56	<0.001
Reefs (Treatment)	4	1.37	0.27	0.89
Residual	24	5.12		

Cochran's C = 0.30 (p>0.05)

Table 6.8 An orthogonal sampling design to test for the effects of an impact (such as aquarium fish collecting) at a number of replicate locations and the same number of control locations. a = number of treatment types (in this scenario a = 2 because there are only impact and control treatments); b = number of reefs of each treatment type. For this hypothetical scenario, Treatments = 2 (collected, uncollected), fixed and orthogonal; Reefs = 3 (there are three reefs from which collecting occurs and three reference reefs where no collecting has occurred) nested in Treatments; Replicates = 5 (five replicate transects are surveyed in the same habitat at each reef.

aquarium fish collecting five years after a permit for collecting had been issued. Another would be a survey to assess the performance of a no-take marine reserve five years after its establishment, where no surveys had been undertaken prior to, or during the activity. ACI designs are useful when there is no 'before' data, although they provide less powerful evidence than a before-after comparison. The ability of an ACI design to establish that an impact has occurred is greatly improved when surveys are repeated on several occasions. ACI designs are useful when management regimes are put in place over activities that may have been operating in an area for several years before management began.

The basis of the ACI study is that a disturbance is assessed at the potentially impacted locations and at the same number of locations where the activity is not occurring. The following design and analysis are useful where the activity in question occurs at more than one location. In this hypothetical scenario three affected reefs are randomly selected from amongst the total group of affected reefs. Three similar reefs are also randomly selected from the total group of reefs where the activity in question does not occur. Control reefs are similar to the potentially impacted reefs in all aspects (reef type, habitats, depth, exposure and other human uses) apart from the presence of the activity in question. In this scenario surveys were undertaken to test the null hypothesis that aquarium fish collecting has not affected the overall density of *Acanthurus sohal*. However, the reefs used in the example were not large enough to allow replicate sites within each reef to be sampled. The data used are presented in Appendix 6.7.6 and the form of the ANOVA used to test the hypothesis is shown in Table 6.8.

The data analysis showed a significant difference in density of *Acanthurus sohal* between collected and uncollected reefs, but no significant difference in density of *A. sohal* between reefs in each treatment.

More powerful conclusions about the spatial extent of impacts are possible in situations where nesting of replicate sites is possible (such as, where a human activity occurs at the scale of an entire reef and the affected reefs are large enough to allow for replicate nested sites to be sampled). Replicate sites represent the same habitat type and are similar to one another in all aspects. The advantage of using replicate sites nested within each reef is that it allows conclusions to be drawn about the spatial consistency of the results (UNDERWOOD 1997). For example, it may show that fish density may be reduced by collecting in one site on the reef but not in others. Hypothetical data for this scenario are given in Appendix 6.7.7 and the sampling design and results of the analysis of variance for a test of the scenario are shown in Table 6.9.

The survey showed that there was a significant difference between the collected and uncollected reefs in density of *Acanthurus sohal*. Examination of the plots of mean densities shows that densities of *A. sohal* at the collected reefs were, on average, less than half the density at uncollected reefs. The analysis also revealed a significant difference between reefs (Treatment) but no significant difference between sites at each reef.

Source of variation	**Fixed (F), Random (R), Nested (N)**	**df**	**MS denominator**
Treatment	F	a-1	Reefs (Treatment)
Reefs (Treatment)	R, N	a(b-1)	Sites (Treatment x Reef)
Sites (Treatment x Reef)	R, N	ab(c-1)	Residual
Residual	R	abc(n-1)	

Summary of results of ANOVA.

Source of variation	**df**	**MS**	***F*-ratio**	***P***
Treatment	1	1361.11	91.69	<0.001
Reefs (Treatment)	4	14.84	3.70	<0.05
Sites (Treatment x Reef)	12	4.01	1.14	>0.25
Residual	72	3.53		

Cochran's $C = 0.15$ ($p>0.05$)

Table 6.9 Sampling design to test for the effects of an impact (such as aquarium fish collecting) at a number of replicate locations and the same number of control locations, with replicate sites nested in each location. For this hypothetical scenario Treatments = 2 (collected, uncollected), fixed and orthogonal; Reefs = 3 (there are three reefs from which collecting occurs and three reference reefs where no collecting has occurred) nested in Treatments; Sites = 3 (random and nested in Treatment x Location); Replicates = 5 (five replicate transects are surveyed in the same habitat at each reef).

Before-After Control-Impact Designs

Designs involving surveys done at one time and involving only one impact and one control location are the simplest. The test for an impact is confounded, however, because of the lack of replication of locations. Any difference detected between the two locations may be due either to the activity in question or to natural differences between the two locations.

Improvements to this design involve an increase in the number of control locations. In this case, differences between the impact location and several control locations are more likely to be due to the impact and less likely to be due to underlying differences between all locations. These designs have the drawback of lacking any observation of change, so it is impossible to prove with certainty that they were not different before the impact occurred. Control and impact locations are likely to differ from one another after an impact, simply because of naturally occurring spatial variation (GREEN 1979). It therefore becomes important to understand the differences that existed between the control and impact locations before the impact occurred, as well as after the impact. The sampling design and analysis for detecting impacts is known as the Before-After Control-Impact or BACI design. The key comparison involves testing for changes at the impact location from before to after the impact and changes at the control location from before to after the impact. Such a sampling design provides information on how abundances vary through time both before and after the impact (UNDERWOOD 1992).

A powerful sampling design for detecting impacts involves the sampling of multiple impact locations and multiple control locations and is called the MBACI design

Source of variation	**Fixed (F), Random (R), Nested (N)**	**df**	**MS denominator**
Treatment	F	a-1	Location (Treatment)
Location (Treatment)	R, N	a (b-1)	Residual
Time	F	(c-1)	Location (Treatment) x Time
Sample (Time)	F, N	c (d-1)	Location (Treatment) x Sample (Time)
Treatment x Time		(a-1)(c-1)	Location (Treatment) x Time
Treatment x Sample (Time)		(a-1)c(d-1)	Location (Treatment) x Sample (Time)
Location (Treatment) x Time		a (b-1) (c-1)	Residual
Location (Treatment) x Sample (Time)		a(b-1)c(d-1)	Residual
Residual		abcd(n-1)	

Table 6.10 A Multiple Before-After Control-Impact (MBACI) sampling design (modified from KEOUGH & MAPSTONE (1995) and KINGSFORD & BATTERSHILL (1998) in which there are 'a' Treatments (in this case a = 2 for Impact and Controls); 'b' Locations nested in each Treatment; 'c' Times (in this case c = 2 for Before and After); 'd' Sample occasions in each Time; and 'n' replicate sample units.

(KEOUGH & MAPSTONE 1995). In this design multiple impact locations and multiple control locations are sampled at multiple times before the impact and for multiple times after the impact. The sampling design and analysis for this is shown in Table 6.10. In this sampling design an impact would be signified by a significant Treatment x Times interaction, (for instance, the two treatments differed in their pattern of change through time).

Asymmetrical Designs

Frequently, in studies of environmental impact there is only one location where a disturbance has occurred, such as an oil spill, sewage outfall or ship grounding. Similarly, there is often only one location where a management intervention has been applied, such as the establishment of a single no-take marine reserve. The disturbed or managed location is frequently surrounded by several comparable locations where the disturbance or management has not occurred. In this scenario there is a single potentially impacted location and several control locations. These therefore require 'asymmetrical' designs to test for significant differences between the disturbed and control locations (UNDERWOOD 1992, 1993).

Asymmetrical designs are appropriate in situations where there is only one disturbed location and several comparable control locations. Simplification of the analysis by use of only one reference location would not be ecologically valid because of the high degree of spatial variability that naturally exists in marine systems. For example, a single control location may have unusually low numbers of the target species because of local differences in circulation patterns that reduce the level of recruitment to this location. In this situation no difference might be detected between the disturbed location and the control location and the activity would be regarded as having no impact. Comparison of a disturbed location with several control locations will allow a comparison with the general condition of locations in the area.

Detecting the effects of the activity or event in these situations becomes more complex because there are unequal numbers of disturbed and control locations. In this situation two analyses are required to separate the effects of the disturbed location from the control locations (UNDERWOOD 1993; GLASBY 1997). Tests of this design have low power because of the small number of degrees of freedom in the numerator mean square of the F–ratio. Power can be improved by increasing the number of control locations that are sampled or pooling non-significant terms (GLASBY 1997).

The data in the following example come from an ongoing study by the author into the effects of declaration of a marine reserve in south-east Australia on the density of key species of rocky reef fishes (GLADSTONE 2001). An asymmetrical design was used because there is only one no-take marine reserve and use of multiple control locations avoids problems with pseudoreplication (HURLBERT 1984). Two control locations were surveyed and there were two sites nested within each location (including the marine reserve). The reserve was declared in 1973 and because no data was collected on the status of fish populations before declaration, the design and analysis are a form of asymmetrical ACI design.

The asymmetrical ANOVA was undertaken in the following steps:

a) An ANOVA was performed for the complete design with no distinction between protected and unprotected locations;

b) A second ANOVA was performed on just the two control locations;

c) The Sums of Squares (SS) for the comparison of Protected vs Control locations was determined by subtracting the SS for the Control locations obtained in step b from the SS for the Locations obtained in step a.

The Mean Squares (MS) denominator used in the calculation of the *F*–ratio for the main comparison of Protected vs Control locations was the MS for Locations determined in step b. This usually results in a comparison with very low power due to the small number of degrees of freedom for this design, (1,1). The power of this comparison can be improved if a non-significant difference is detected between Sites within Control Locations at $p>0.25$. In this case the MS denominator for the comparison of Protected vs Control Locations was determined by pooling SS for Controls, Sites within Reference Locations and Residual from the ANOVA in step b. This increased the degrees of freedom from 1,1 to 1,33 and hence the power of the test (GLASBY 1997). The design and analyses are shown in Table 6.11.

Source of variation	**Fixed (F), Random (R), Nested (N)**	**df**	**MS denominator**
Reefs		a-1	
Reserve	F	a-b	Controls*
Controls	R	b-1	Sites (Reefs)
Sites (Reefs)		a(c-1)	
Sites (Reserve)	R, N	a(c-1)- b(c-1)	Residual
Sites (Controls)	R, N	b(c-1)	Residual
Residual		ac(n-1)	

* when Sites (Controls) are non-significant at P>0.25, MS Reserve can be tested against a pooled MS denominator consisting of Controls + Sites (Controls) + Residual (for further details see WINER 1971; UNDERWOOD 1993; GLABSY 1997).

Species richness of fishes

Source of variation	**SS**	**df**	**MS**	**MS denominator**	***F*-ratio**
Reefs	205.39	2	102.69		
Reserve	203.35	1	203.35	Pooled Controls + Sites (Controls) + Residual	43.45 *P*<0.05
Controls	2.04	1	2.04	Sites (Reefs)	0.75 NS
Sites (Reefs)	8.17	3	2.72		
Sites (Reserve)	0.75	1	0.75	Residual	0.15 NS
Sites (Controls)	7.42	2	3.71	Residual	0.73 NS
Residual	151.67	30	5.05		

Table 6.11 Asymmetrical sampling design used to test for differences in fish assemblages between a single marine reserve and two control locations. A total of three locations were surveyed representing a = 1 reserve location and b = 2 control locations; c = 2 sites were nested in each location and n = 6 replicate 5 x 25 m transects were surveyed in each site.

The analysis presented in Table 6.11 below revealed a significant difference in fish species richness between the reserve and the control locations. Mean species richness in the reserve (13.0 ± 0.50) was significantly greater than mean species richness in the control locations (8.0 ± 0.48). There were no differences in species richness between replicate sites in both the reserve and the control locations.

Asymmetrical designs can be quite complex when short- and long-term temporal variation are included as factors. Short-term temporal patterns may need to be addressed when the researcher wishes to test the hypothesis that patterns of short-term change (for example, between weeks) are altered in the impacted location compared with the control location. In this case the smaller time interval (weeks) is nested within the larger time interval (for example, months) for the purposes of the statistical analysis. Although they may appear more complicated, the analyses are undertaken with the same principles outlined for asymmetrical ANOVA. Interested readers should consult the literature for further examples of more complicated designs, their calculation and interpretation (UNDERWOOD 1992, 1993; GLASBY 1997; ROBERTS et al. 1998). The following example illustrates these principles.

SMITH et al. (1999) undertook a study to determine the impacts of exposure to sewage on fish populations. Surveys were conducted on fish populations at three locations. One location was at the proposed sewage outfall and two control locations (without sewage outfalls) were selected with the same habitat type. Surveys were undertaken during three periods (before commissioning of the sewage outfall; immediately after commissioning; and one year after commissioning) and there were four sample occasions within each period, making a total of 12 samples. Data were analysed using a three-factor asymmetrical ANOVA (Table 6.12). In this

Source of Variation	**df**	**MS denominator**	**Total abundance**		**Species richness**	
			MS	*F*	MS	*F*
Period (P)	2	Residual	0.28	6.76*	26.30	2.36NS
Time(period) T(P)	9	T(P) x OvC	0.22	3.05NS	24.10	2.66NS
Location (L)	2	T(P) x L	2.74	46.40**	289.00	39.70**
Outfall v Control (OvC)	(1)	T(P) x L(OvC)	4.91	68.20**	569.00	63.00**
Between Controls	(1)	T(P) x L(controls)	0.56	12.50**	10.00	1.80NS
Period x Location	4	T(P) x L	0.06	0.98NS	36.30	4.98**
Period x OvC	(2)	T(P) x L(OvC)	0.08	1.08NS	69.50	7.69*
Period x Controls	(2)	T(P) x L(controls)	0.04	0.84NS	3.17	0.35NS
Time(period) x Location	18	Residual	0.06	1.40NS	7.29	0.65NS
Time(period) x OvC	(9)	T(P) x L(controls)	0.07	1.60NS	9.04	1.62NS
Time(period) x Controls	(9)	Residual	0.04	1.07NS	5.56	0.50NS
Residual	106		0.04		11.15	

Table 6.12 Summary of asymmetrical ANOVA results comparing fish abundance and species richness at one location with a sewage outfall and two control locations (modified from SMITH et al. 1999). Degrees of freedom (df) for repartitioned sources of variation are shown in brackets. NS – $p>0.05$; * – $p<0.05$; ** – $p<0.01$.

design an impact could be attributed to the sewage if the interaction term Period x Outfall versus Control (OvC) was significant and Period x Controls was non-significant. The former would indicate that the difference between the outfall and the control locations changed through time.

No effect of the sewage outfall was detected for total abundance of all fishes (Table 6.12). There was, however, a significant change in species richness at the sewage outfall following its commissioning (indicated by the significant F–ratio for Period x OvC). In fact, SMITH et al. (1999) found that fish species richness had declined by 33% at the sewage outfall. Based on the results of the surveys, the authors concluded that the sewage outfall operations were not complying with agreed industry standards for the ecologically sustainable disposal of sewage.

6.3.3 Multivariate Methods

The sampling designs and related analyses discussed so far deal with single species and single variables, such as density or length of a species. In practice, this is done out of interest in a particular species, such as one that may be targeted by aquarium fish collectors or a species known to be targeted by fishermen. Alternatively, it may be done because a single species, or group of species, is thought to be an indicator of changes occurring in the rest of the fish community. In other situations it may also be important to describe patterns and changes in the entire community or assemblage of fishes. This can arise from a desire to describe biogeographic patterns in regional ichthyofauna, to determine whether different habitats are occupied by different assemblages of fishes, to evaluate changes in the entire fish assemblage resulting from a management intervention or from the removal of a group of fishes believed to be important in structuring fish communities (for example, removal of piscivorous fishes by fishing).

Multivariate methods are an alternative to summary statistics that attempt to describe an assemblage through a single number, such as species richness, evenness and diversity. Datasets consist of a matrix of samples and species abundances and can be quite complex when several hundred species are surveyed. The objective of multivariate methods is to simplify these complex datasets and analyse them in one of two ways. Firstly, they can search for patterns among samples about which there is no prior hypothesis. Second, they can test for differences in assemblage composition between groups defined *a priori* (such as habitats or reefs subjected to different fishing intensities).

Excellent descriptions of multivariate methods, and their value in assessment and monitoring, are provided by CLARKE (1993); MANLY (1994); and CLARKE & WARWICK (2001). Multivariate methods consist of procedures to calculate measures of similarity between samples, leading to the determination of a similarity matrix, by using a measure such as the Bray-Curtis similarity coefficient (CLARKE 1993). Some form of data transformation may be required prior to calculation of the similarity measure when samples consist of species with wide differences in abundances. Transformation reduces the overwhelming importance of a few species occurring at high densities and increases the importance of species represented by only a few individuals. Similarities between samples are depicted visually by reducing the complexity of the multivariate dataset to two-dimensional plots. They can be presented either as dendrograms, using cluster analysis, or as ordinations, by processes such as principal components analysis (PCA) or non-metric multi-dimensional scaling (MDS).

More recent developments in multivariate methods have allowed for testing of the statistical significance of differences between groups of samples identified *a priori*, or groups suggested by ordinations or dendrograms. Existing tests, called analysis of similarities (ANOSIM), are based on randomisation procedures and are suitable for one-way, two-factor orthogonal and nested sampling designs (CLARKE 1993; CLARKE & WARWICK 2001; but see ANDERSON 2001). The power of these tests can be low in sampling designs where there are only small numbers of the nested factor (for example three or fewer sites in each location). In these situations, the evaluation of differences between groups relies on examination of the relative magnitude of similarity measures (CLARKE 1999). However, recent developments in multivariate analysis of variance, called non-parametric multivariate analysis of variance or NPMANOVA (ANDERSON 2001) allow tests of these less powerful sampling designs.

Multivariate methods allow for examination of the causes of differences between groups of samples. They can do so by providing tests of the strength of correlations between groups of samples and environmental measures recorded at the same time, such as depth, coral coverage, sediment composition, salinity and turbidity (CLARKE & AINSWORTH 1993).

WARWICK & CLARKE (1993) used multivariate methods to test for an effect of coral mining activities on the assemblages of fishes on reef flats in the Maldive Islands. Twenty three sites were surveyed, representing 11 mined sites and 12 control sites. Using non-metric MDS ordinations based on Bray-Curtis similarity measures, the authors demonstrated that assemblages in mined sites were different from those occurring at control sites (Figure 6.1). The authors also found that variability between samples was greater at the mined sites than at the control sites and suggested that increased

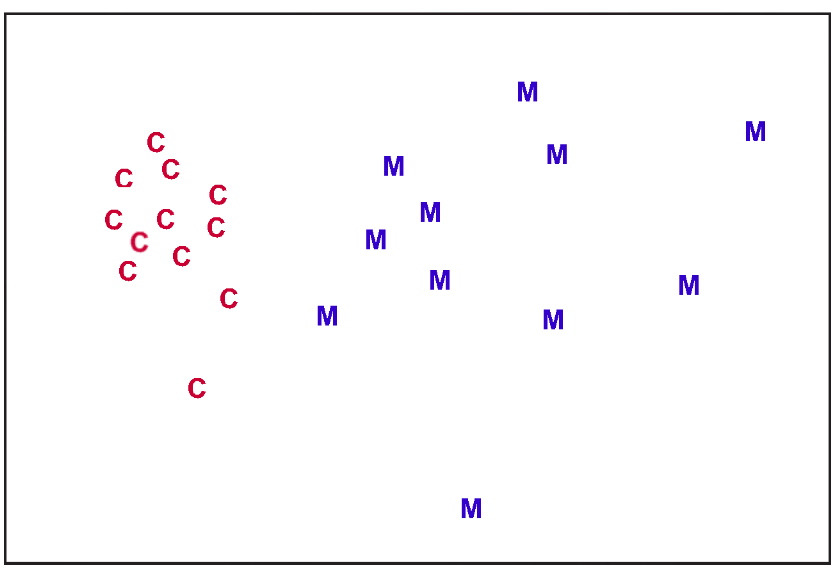


Figure 6.1 Non-metric multi-dimensional scaling (MDS) ordination illustrating differences in fish assemblages on reef flats of the Maldive Islands between sites subjected to coral mining (M) and control sites (C). Clustering of sites on the MDS ordination indicates greater similarity in the composition of their fish assemblages compared with sites placed more distantly on the ordination (from CLARKE & WARWICK 2001).

variability might be a sign of disturbance. SWEATMAN (1997) used ordinations derived from PCA to test for the existence of cross-shelf patterns (such as inshore, mid-shelf, and outer-shelf reefs) in the composition of fish assemblages. The ordinations suggested there were strong cross-shelf patterns as reefs at each shelf position contained distinct fish assemblages. Further analysis revealed that reefs separated more clearly when classified according to their relative exposure to prevailing winds. This suggested that the most important underlying ecological process structuring reef fish assemblages was the degree of exposure, not the position of the reef on the continental shelf. There was only a limited effect of latitude on reef fish assemblages, with only a small proportion of fishes showing distinct latitudinal trends in abundance. SMITH et al. (1999), used one-way ANOSIM (the multi-variate equivalent of one-way ANOVA) to assess fish assemblages at the location impacted by the sewage outfall. They found that the fish assemblages at the impacted location differed significantly from those occurring at two control locations after operations commenced at the sewage outfall.

6.4 DATA PRESENTATION

Data collected during surveys and monitoring is presented in a variety of formats, such as in written publications (as tables, figures, maps, drawings, photographs), as part of spoken presentations and as conference posters. The data can be complex when the sampling design includes factors such as locations, sites nested within locations, reef zones, and a number of times. Modern workplaces are usually very busy, so the data and the accompanying description are probably going to be read by people who have a limited amount of time to read and comprehend the information. Given that this information is to be used for purposes of informing decision makers, scientists and the general community, effective presentation of these complex datasets becomes a very important task and one that is almost as important as the data collection itself.

The following principles of effective scientific data presentation are synthesised from the excellent treatments of this topic by TUFTE (1983) and QUINN & KEOUGH (2002). The principles are generally applicable to the presentation of scientific data, rather than specific to the presentation of data from surveys and monitoring of fishes.

6.4.1 Presenting the Results of Analyses

Regression analyses are used to test hypotheses about the relationship between two variables and involve a single predictor variable (such as depth) and a dependent variable (such as fish density). The results that will convey the most useful information to the reader include the regression equation, the r^2 value, the test statistic for the slope of the regression line, its significance level and the number of degrees of freedom. QUINN & KEOUGH (2002 p. 495) provide the following example for presenting the results of a regression analysis to explain the relationship between limpet abundance and coverage of algae. They state,

> "The number of limpets fell as algal cover increased, although algal cover only explained 12% of the variation in limpet abundance (equation: log(limpets) = 1.076–0.006 x algal cover, $F_{1,38}$ = 5.129, p = 0.029, r^2 = 0.119)".

Results of more complex multiple regressions are best presented in tabular form rather than as a series of equations in the text.

Results of an ANOVA can be presented as the complete ANOVA table (see Tables 6.7, 6.8 and 6.10) including at least the degrees of freedom, mean squares, the error terms (for complex ANOVA models) and *P*–values. However, this is not usually necessary for single factor ANOVA models. In the latter case, the information can usually be presented in the text, for example:

> "Frequency of attacks by the lizardfish *Synodus englemani* on prey fish did not differ between 1 hour periods throughout the day ($F_{12,88} = 0.79$, $p > 0.05$)" (SWEATMAN 1984).

In orthogonal analyses of variance where there are significant differences between levels, the results of multiple comparisons can be presented in two ways. Non-significantly different means in graphs and tables can be labelled with the same letter or groups of such means can be underlined. Significant interactions can also be illustrated in graphs of the means of each level (QUINN & KEOUGH 2002).

6.4.2 Tabular Presentations of Data

Data suitable for presentation in tables include summaries of statistical analyses, summary data (such as the mean and some estimate of its error) and raw data (usually presented in appendices). It is also possible to present an overview of trends from the results of many different statistical analyses in an illustrative summary table. Ticks can then be used to highlight significant results and crosses for non-significant results. Many software packages include options for constructing tables. However, many of the format choices are stylish and inappropriate to the scientific presentation of results. Tabular presentations must aim to make the reader's job of assimilating the data as easy as possible.

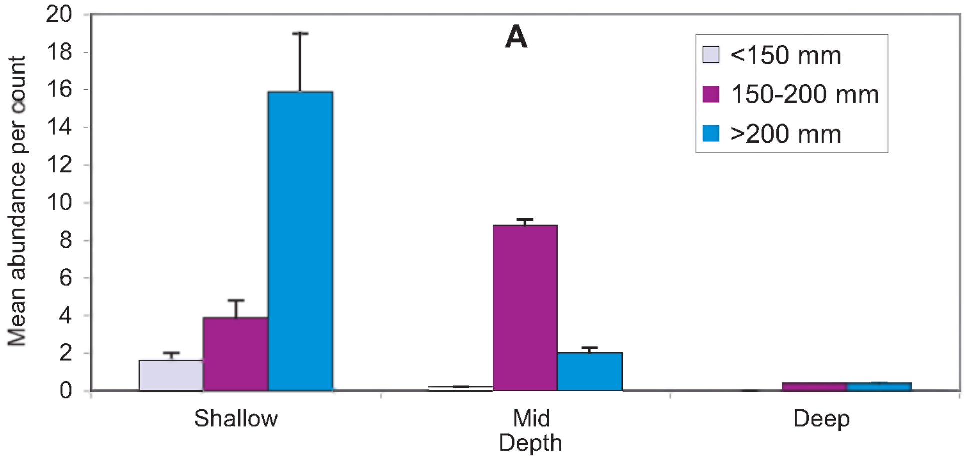
6.4.3 Graphical Presentations of Data

Graphical presentation of data provides a means for interpreting data (for example, by displaying trends) and presenting results. Effective use of graphs will increase the reader's comprehension of complex datasets. Most modern statistical software (such as SPSS and SYSTAT) and some spreadsheet software packages (such as EXCEL), provide options for graphical presentation of data. Options available include graph and fill types and a variety of symbols and colours. Although visually attractive, inappropriate use of these options may obscure the information that is being presented in the graph. The content of the graph should be the focus, not its design, and graphs should present large amounts of data in a coherent manner.

Graphs should be used to draw the reader's attention to the most important aspects of results (QUINN & KEOUGH 2002). For example, comparisons between treatments (such as between locations, reef zones or depths) should be emphasised in graphs (Figure 6.2).

TUFTE (1983) outlined a number of guiding principles for the construction of graphs:

- Graphs with a high data:ink ratio are preferred, where the 'ink' refers to the amount of ink needed to print the graph.
- Graphs with a high data density are preferred, where 'data density' is the amount of space taken up by the graph.
- Graphs should not have extraneous 'chart junk', which is ornamentation on a graph not necessary for the presentation of the data and includes



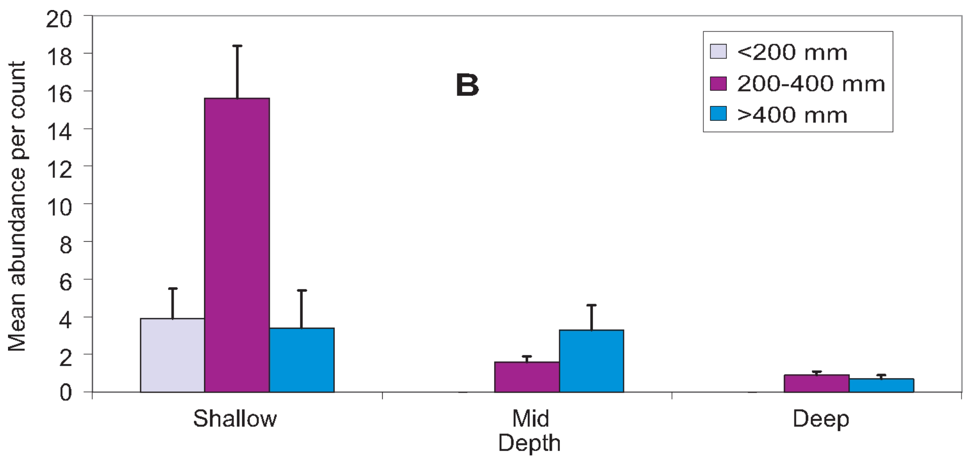


Figure 6.2 Mean abundance (± standard deviation, n = 12) of (A) *Parma alboscapularis* and (B) *Girella tricuspidata* of different size classes at three depths (adapted from MEEKAN & CHOAT 1997).

features such as excessive gridlines and graph headings (there is no need for these as they are usually described in the legend of the graph).

The type and appearance of graph required should vary with its context. Graphs in a paper or written report can be quite complex because the reader has the time to think about the trends depicted. On the other hand, graphs used in oral presentations will usually need to be less complicated, because time is usually short and they should make more effective use of colours and shades to illustrate different treatments (QUINN & KEOUGH 2002). Bar graphs are used to plot a quantitative variable on the Y–axis, such as fish density, against a categorical variable on the X–axis, such as reef zone (Appendix 6.7.7). The height of the bar represents a single value such as total abundance, or a summary variable, such as mean density. Where a mean value is plotted it will also be necessary to include a measure of its error, such as standard deviation or standard error (see Appendix 6.7.7). Multiple categorical variables, such as replicate sites within locations, can be represented by multiple bars adjacent to one another, each with its own estimate of error (see Figure 6.2). Bars depicting multiple categorical variables can be presented with different fill patterns. However, it is preferable for these fill patterns to be as simple as possible (for example, in black, white or grey) rather than various

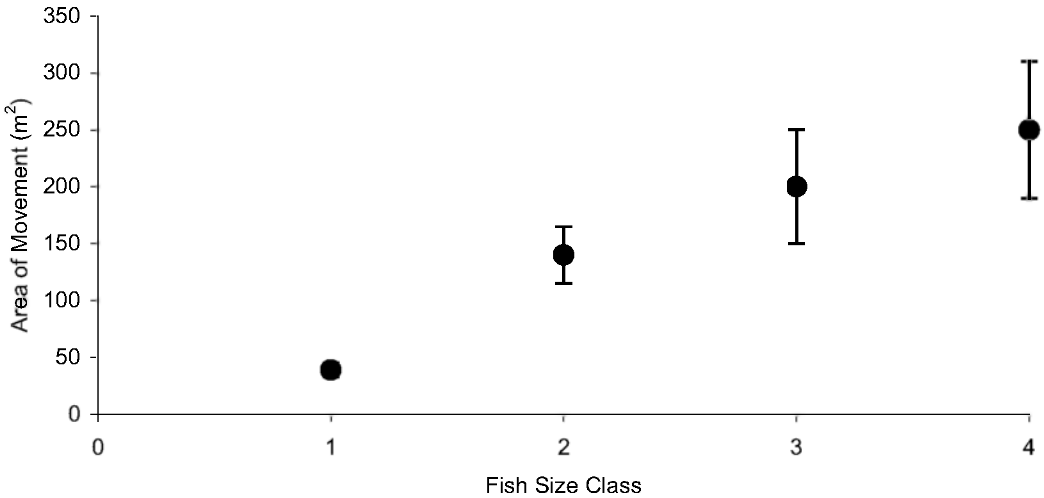


Figure 6.3 Area of movement in 15 minutes for four size classes of coral trout in spring. Size classes are: 1: < 31 cm total length (TL); 2: 31–45 cm TL; 3: 46–60 cm TL; 4: > 60 cm TL. N = 16. Error bars are standard errors (adapted from SAMIOLYS 1997).

degrees of shading. This will allow for easier interpretation at lower print quality and facilitate multiple photocopying.

As a general rule-of-thumb, QUINN & KEOUGH (2002) recommend that three dimensional graphs should not be used for two dimensional data. Thus data that could normally be presented clearly as a bar graph or line graph should not be presented in a three dimensional format. Three dimensional graphs ignore the principle of TUFTE (1983) of achieving a high data:ink ratio.

Line graphs are used for presenting data in which the categorical variable on the X–axis can be ordered (for example shallow, medium, deep) or in situations where it is quantitative, such as a time series. The top of the bar graph is replaced by a symbol and different symbols can be used to represent additional grouping variables (for example shallow, medium and deep at three different locations). There is no need for a line to be used to connect the symbols (although it may help some readers interpret the data) because it does not imply any relationship between the X and Y variables (see Figure 6.3). Where the symbol is being used to represent the mean, error bars should also be included. In presentations of complex datasets it may be difficult to interpret errors when there are many symbols and overlapping error bars. In such situations the data presentation may be improved by only plotting the smallest and largest errors or by plotting only one half of the error bar (QUINN & KEOUGH 2002). In complex sampling designs the choice of error to plot may not be clear as it will depend on the hypothesis being tested and consequently, the error term used to test the hypothesis. QUINN & KEOUGH (2002) provide a detailed explanation of the alternatives.

Scatter plots are useful for exploring relationships between two variables, such as those normally explained by correlation or regression statistics. Lines fitted to describe regression relationships (for example length–weight relationships) should not extend beyond the data points to an intercept with the Y–axis (unless the dataset includes a zero X–value). This is because nothing is known about the relationship between the two variables outside of the set of data available.

Confidence intervals or ellipses can also be fitted around the regression line to indicate the degree of error (QUINN & KEOUGH 2002). TUFTE (1983) and QUINN & KEOUGH (2002) argue that pie charts should never be used for scientific data presentation because of uncertainty about their interpretation and because they have a low data:ink ratio and low data density.

6.4.4 Oral Presentations

The majority of the preceding information relates to data presentations for written material, such as scientific papers and reports. Many of these principles are applicable to oral presentations, especially the construction of tabular and graphical presentations of data. However, there are additional considerations for oral presentations. Oral presentations can be done with overheads, slides or computer projections. The choice will depend on the equipment available and the environment at the venue (such as the light levels and the distance to the screen). Although sometimes cumbersome to prepare, slides are easy to transport, they project clearly because of their high resolution, they allow a combination of images and text to be presented and the technology to project them is available at most venues. Overheads allow for changes to be made to content immediately before or during the presentation, although the quality of overhead projections rapidly diminishes as the ambient light levels increase and as the distance between the projector and the screen increases. Computer projections are flexible, offering a great range of presentation styles, rapid modification of presentations, the easy incorporation of images into text, colours and other visual effects. Modern software packages such as MICROSOFT POWERPOINT, also allow for handouts to be produced for distribution prior to the presentation. The major constraints to computer projection include lack of facilities, incompatibility of software versions and corruption of storage media.

QUINN & KEOUGH (2002) offer the following advice when graphics packages are used to prepare presentations:

- Aim for simple backgrounds that are either uniform or lightly graded
- Use a minimum of fonts
- Use the simplest possible slide transitions
- If using colours, choose from amongst the designs available in the programme rather than designing your own set of colour combinations
- Use solid fills on graphs to distinguish groups of data
- Use scanned images inserted into the presentation to eliminate the need to switch between slide projector and computer projector. Scanned images can be saved at a low resolution and with a reduced number of colours to reduce the file size.

The audience at an oral presentation has less time to assimilate the information than a reader of a report or scientific paper. This means that decisions will have to be made about the information content of oral presentations that allow for audience comprehension and understanding. Avoid preparing oral presentations with large amounts of information on each slide, where the audience will spend most of their time reading the text rather than listening. This is particularly important for audiences whose first language differs from that of the presenter. All unnecessary content should be removed from figures and the presenter should guide the audience through the figures by explaining the meanings of the symbols and the trends being displayed. In this way the speaker will retain control over the information being presented.

6.5 DECISION MAKING

Decision making in environmental assessment and monitoring is probabilistic when done in the framework of hypothesis testing and inferential statistics (UNDERWOOD 1990; KEOUGH & MAPSTONE 1995; MAPSTONE 1995). This probabilistic nature of decision making arises from the existence of great variability in natural systems and the way such variability is measured. Variability in most parameters measured as part of surveys and monitoring occurs spatially and temporally. For example, population sizes vary through time as a result of recruitment and mortality and between locations as a result of patchiness in recruitment and differences in essential resources. Furthermore, spatial and temporal variability may not be independent. For instance, locations may differ in the way they change through time, making it impossible to generalise about either spatial or temporal patterns in a parameter. In addition, there will always be variation in the measurements of these parameters because of technological limitations, human error and procedural errors. Consequently, measurements of a parameter taken at a few locations and/or a few times will not adequately represent the general status of that parameter. It is also very difficult to measure a parameter without error. This means that it is not possible to be absolutely certain whether or not a difference exists. In the framework of the scientific approach it is only possible to decide that a difference exists (or does not exist) with a certain probability of error (KEOUGH & MAPSTONE 1995). The use of statistical tests renders decision making probabilistic and there will always be the risk of errors in the results of statistical tests (see Table 6.13).

Decision making, in the face of this natural variability, will be improved by:

- Use of sampling designs that are appropriate to the hypothesis being tested,
- Use of statistical tests to describe patterns in results and to provide probabilities for the results, and
- Establishing sets of decision rules prior to the commencement of the surveys and monitoring (MAPSTONE 1995).

Decision making becomes critical when done in the context of environmental assessment, such as in determining whether or not an impact has occurred as a result of human activity. Such a decision can have environmental, social and economic consequences when it must be decided whether to stop an activity, whether to undertake some form of remediation or whether to change the management activity in question. In this context, considerations of Type I and Type II error rates in the design of survey and monitoring programmes assume practical significance (see Table 6.13).

The risk of making Type I and Type II errors can be minimised in the design stage of the survey and monitoring programme by specifying an 'effect size' that must be detected if it occurs (KEOUGH & MAPSTONE 1995). Specification of an effect size requires agreement on what level of impact is acceptable or what magnitude of difference (for instance, following declaration of a marine reserve) is desired to be detected. The effect size is defined in terms of the parameter being measured (such as density or length of individual species). It may be stated as, "20% reduction in fish density is unacceptable". Effect size may also be defined in social, economic or aesthetic terms (OLIVER 1995). For example, the sustainability of dive tourism in the Caribbean has been assessed in terms of changes it causes to reef aesthetics (PRICE et al. 1998).

Determination of effect size is a critical step in decision making that should occur at the design stage of the survey and monitoring programme. This is likely to be a difficult task

Consider the scenario that a survey and monitoring programme has been undertaken to test whether the abundance of an indicator species differs between reefs where collecting for ornamental fish is allowed and reference reefs where no collecting is occurring. The results of the monitoring programme are important because they will be used by the management agency to decide whether to allow the ornamental fish collecting to continue. There are a number of possible outcomes from the analysis of the survey results, depicted in the table below:

		State of the reef	
		Impact	**No Impact**
Result of test	**Significant impact detected**	correct	Type I error
	No significant impact	Type II error	correct

The Type I error rate is the probability of the test finding a significant difference, when none was actually present. By convention, a Type I error rate of 5% (also known as the alpha (α) significance level) is regarded as an acceptable risk. This means that the probability of the result occurring by chance alone is $\leq$ 5%.

If the test returned a non-significant result, there are two possibilities: there really is no difference between the collected and reference reefs; or alternatively an impact was present but the test was unable to detect it. The risk of the latter occurring is known as the Type II error rate (and is designated as beta, β). Type II error can also be described as a failure to detect an impact when it was actually present. Although there is no convention on the size of Type II error rate, a value of 0.20 if often used in designing survey programmes. The power of a survey and monitoring programme is defined as $1-\beta$, and for the latter case power = 0.80. Survey and monitoring programmes with high power have a reduced risk of Type II error. The occurrence of a Type II error can have serious consequences if it leads to a lack of management action and further environmental degradation. The risk of a Type II error (and therefore the power of a survey and monitoring programme) is influenced by a number of factors including the magnitude of natural variability in abundance of target species, sampling effort, and the degree of change desired to be detected. Change becomes more difficult to detect for species that occur naturally at low densities or have abundances that vary widely and unpredictably through time.

A series of pilot studies will provide information on the natural abundance of an indicator organism, the magnitude of natural variations in its abundance, the sampling strategy required to address this variability, and the degree of change that can be detected for a given level of power. The procedures for undertaking such a study and power analysis are described in ANDREW & MAPSTONE (1987), UNDERWOOD (1981, 1997) and QUINN & KEOUGH (2002).

Table 6.13 The ability of surveys and monitoring to detect change: power analysis.

because information on the ecological, social, and economic significance of changes of varying magnitude may be lacking (KEOUGH & MAPSTONE 1995). However, an effect size should be determined and then adapted (if necessary) as part of the monitoring and review phase. OLIVER (1995) describes the decision-making process undertaken as part of a reactive monitoring programme put in place for the construction of a marina on the Great Barrier Reef. A set of indicator variables (such as coral bleaching or coral mortality) were measured on nearby fringing reefs. Additionally, threshold effect sizes were established during the design phase which, if exceeded, would instigate a range of management actions (including cessation of work on the project). For example, an effect size characterized by 50% colony mortality in 30% of coral colonies, or 60% of colony bleaching in 40% of coral colonies sampled, led to immediate management action. Effect sizes were established *a priori* by a group consisting of coral experts and environmental managers.

Ecologically meaningful effect sizes may be difficult to detect for species existing at low population sizes or species with naturally high variability in density. MARSH (1995) found that a monitoring programme to detect an effect size of a biologically meaningful decline in dugong populations (such as 5% per annum) and probabilities of Type I and Type II errors of 0.1, would require an intensive monitoring programme of monthly aerial surveys over periods of 8–10 years. MAPSTONE et al. (1998) found that, to detect a change of 50% in existing population densities, with probabilities of Type I and Type II errors of 0.1, monitoring of between 19 and 135 reefs (median = 29 reefs) was required for lutjanids and between 2 and 9 reefs (median = 5.5 reefs) for chaetodontids. The required level of replication was also found to differ for monitoring done over the whole reef, in the back reef and in the fore reef. When potential effect sizes were calculated for a monitoring design consisting of four reefs, with probabilities of Type I and Type II errors of 0.1, it was found that differences between two mean densities of 150%, 75% and 57% could be detected for lutjanids, *Plectropomus* spp., and chaetodontids respectively. Effect size estimates at varying probabilities of Type I and Type II errors, for a range of variables can be determined during a pilot or baseline study. These should be undertaken prior to a main survey or monitoring programme (MAPSTONE et al. 1998).

Decision-making strategies may also be imposed from external sources that require a certain effect size to be detected with a low probability of making an incorrect decision. For example, the World Conservation Union's (IUCN) definition of "critically endangered" requires evidence of an 80% decline in population size in the last 10 years, or three generations. Designation as "vulnerable" by the IUCN requires evidence of (amongst other factors) a population decline of at least 50% during the past 20 years, or five generations. MARSH (1995) critically reviewed the difficulties in detecting significant changes in population size for species that occur locally at low population densities.

KEOUGH & MAPSTONE (1995) and MAPSTONE (1995) advocate that, for surveys and monitoring to be useful in decision making, their design should consider a number of factors: the probability of a Type I error and its consequences when an impact is suspected, following rejection of a null hypothesis of 'no impact'; an acceptable probability of a Type II error; and the effect size regarded as being important to detect. This occurs through an *a priori* power analysis of the proposed survey and monitoring sampling design, including calculations of the consequences for detectable effect sizes of changes in sampling effort, Type I and Type II error rates.

Sometimes it may be possible to use estimates of expected variability from published estimates of reef fishes from other regions in the first instance. However, development of regionally relevant survey and monitoring programmes for the Red Sea and Gulf of Aden will require these calculations to be made within the region, in different reef types and different countries, for a range of species of anthropogenic and conservation interest. This initial step in the decision-making process needs to involve scientists and managers, as well as individuals with expertise in the social and economic implications of the potential decisions.

Decisions about sampling effort in relation to effect sizes and Type I and Type II error rates require information about natural variability in the parameter being measured. Formulae for these calculations are outlined in ANDREW & MAPSTONE (1987); PETERMAN (1990); GERRODETTE (1993); TAYLOR & GERRODETTE (1993); MARSH (1995); and UNDERWOOD (1997). Software for power analysis of sampling designs is available in some commercially available statistical programmes (such as SPSS, NCSS) and is also available as free downloads on the internet (see Useful Web Sites – Power Analysis).

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Useful Web Sites

Australian Institute of Marine Science Reef Monitoring:
www.aims.gov.au/pages/research/reef–monitoring/reef–monitoring–index.html
Australian Institute of Marine Science Reef Monitoring: Sampling Design and Methods:
www.aims.gov.au/pages/research/reef–monitoring/methods.html
CRC Reef Research Centre:
www.reef.crc.org.au/about/index.html
FishBase:
www.fishbase.org/search.html
Marine Conservation Biology Institute:
www.mcbi.org/
NOAA Biogeography Program:
biogeo.nos.noaa.gov/
NOAA Coral Health and Monitoring:
www.coral.noaa.gov/bib/lit.abstracts.html
Power: A Primer:
www.pwrc.usgs.gov/powcase/
Power Analysis of Monitoring Programs:
www.pwrc.usgs.gov/powcase/
Power Analysis Resources:
www.pwrc.usgs.gov/powcase/
Reef Base:
www.reefbase.org/
Reef Check:
www.reefcheck.org/
Reef Fish Spawning Aggregations Monitoring Program:
www.conserveonline.org/2003/01/s/en/Spag_protocol_for_Caribbean_GCFI.pdf
Reef Fish Survey Project:
www.reef.org/data/surveyproject.htm
Reef Resource Assessment Calculation Tools:
www.spc.org.nc/artreact.htm
Review of Statistical Power Analysis Software:
www.zoology.ubc.ca/~krebs/power.html
Society for the Conservation of Reef Fish Aggregations:
www.scrfa.org/
Video sensing of reef fishes:
www.aims.gov.au/pages/research/video-sensing/index.html
World Commission on Protected Areas:
www.iucn.org/themes/wcpa/

Appendix 6.7.1 Reef Check survey sheets for the Red Sea (Source: www.reefcheck.org).
Transect surveys

Site Name:			
Depth:		Team Leader:	
Date:		Time:	

Red Sea Belt Transect : Fish

Data recorded by:							
	0-20m	**25-45m**	**50-70m**	**75-95m**	**Total**	**Mean**	**SD**
Butterflyfish							
Sweetlips (*Haemulidae*)							
Snapper (*Lutjanidae*)							
Broomtail wrasse (*Cheilinus lunulatus*)							
Grouper >30cm (Give sizes in comments)							
Bumphead parrotfish (*Bolbometopon muricatum*)							
Humphead wrasse (*Cheilinus undulatus*)							
Any parrotfish (>20cm)							
Moray eel							

Red Sea Belt Transect : Invertebrates

Data recorded by:							
	0-20m	**25-45m**	**50-70m**	**75-95m**	**Total**	**Mean**	**SD**
Banded coral shrimp (*Stenopus hispidus*)							
Diadema urchins							
Pencil urchin (*Heterocentrotus mammillatus*)							
Sea cucumber (edible only)							
Crown-of-thorns star (*Acanthaster planci*)							
Giant clam (*Tridacna*)							
Triton shell (*Charonia tritonis*)							
Lobster							

For each segment, rate the following as: None=0, Low=1, Medium=2, High=3

Coral damage: Anchor				
Coral damage: Dynamite				
Coral damage: Other				
Trash: Fish nets				
Trash: Other				

Comments:	
Grouper sizes (cm):	
Bleaching (% of coral population):	
Bleaching (% per colony):	
Suspected disease (type/%):	
Rare animals sighted (type/#):	
Other:	

Site Descriptions

Site name:

BASIC INFORMATION

Country: ______ State/Province: ______ City/town: ______

Date: ______ Time: Start of survey: ______ End of survey: ______

Latitude (deg. min. sec): ______ Longitude (deg. min. sec): ______

From chart or by GPS? (If GPS, indicate units): Chart______ GPS______ GPS units: ______

Orientation of transect: N-S______ E-W______ NE-SW______ SE-NW______

Temperature (in degrees C): air: ______C surface: ______C at 3m: ______C at 10m: ______C

Distance from shore (m): ______ from nearest river (km): ______

River mouth width: <10 m ______ 11-50 m ______ 51-100 m ______ 101-500 m ______

Distance to nearest population center (km): ______ Population size (x1000): ______

Weather: sunny ______ cloudy ______ raining ______

Visibility (m) : ______

Why is this site selected: ______ Is this best reef in the area? Yes: ______ No : ______

IMPACTS:

Is this site: Always sheltered: ______ Sometimes: ______ Exposed: ______

Major coral damaging storms Yes: ______ No ______ If yes, When was last storm: ______

Overall anthropogenic impact	None: ______	Low: ______	Med: ______	High: ______
Is siltation a problem	Never: ______	Occasionally: ______	Often: ______	Always: ______
Blast fishing	None: ______	Low: ______	Med: ______	High: ______
Poison fishing	None: ______	Low: ______	Med: ______	High: ______
Aquarium fishing	None: ______	Low: ______	Med: ______	High: ______
Harvest inverts for food	None: ______	Low: ______	Med: ______	High: ______
Harvest inverts for curio sales	None: ______	Low: ______	Med: ______	High: ______
Tourist diving/snorkeling:	None: ______	Low: ______	Med: ______	High: ______
Sewage pollution (outfall or boat)	None: ______	Low: ______	Med: ______	High: ______
Industrial pollution	None: ______	Low: ______	Med: ______	High: ______
Commercial fishing (fish caught to sell for food)	None: ______	Low: ______	Med: ______	High: ______
Live food fish trade	None: ______	Low: ______	Med: ______	High: ______
Artisinal/recreational (personal consumption)	None: ______	Low: ______	Med: ______	High: ______
How many yachts are typically present within 1km of this site	None: ______	Few (1-2): ______	Med (3-5): ______	Many (>5): ______

Other impacts:

PROTECTION:

Any protection (legal or other) at this site? Yes: ______ No: ______ If yes, answer questions below

Is protection enforced Yes: ______ No: ______

What is the level of poaching in protected area? None: ______ Low: ______ Med: ______ High ______

Check which activities below are banned:

- Spearfishing ______
- Commercial fishing ______
- Recreational fishing ______
- Invertebrate or shell collecting ______
- Anchoring ______
- Diving ______
- Other (please specify) ______

Other comments ______

TEAM INFORMATION

Submitted by ______

Regional Coordinator: ______

Team Leader: ______

Team Scientist: ______

Team Members: ______

Appendix 6.7.2 Species recommended for monitoring in the Red Sea and Gulf of Aden.

Species to be recorded in 50 x 5 m transects

Family	**Species**
Serranidae	*Cephalopholis hemistiktos*
	Cephalopholis miniata
	Aethaloperca rogaa
	Epinephelus fasciatus
	Epinephelus fuscoguttatus
	Epinephelus summana
	Epinephelus malabaricus
	Epinephelus aerolatus
	Epinephelus chlorostigma
	Plectropomus maculatus
	Plectropomus truncatus
	Pseudanthias squamipinnis
Lutjanidae	*Lutjanus ehrenbergi*
	Lutjanus kasmira
	Lutjanus bohar
	Macolor niger
Haemulidae	*Plectorhinchus pictus*
	Plectorhinchus schotaf
Lethrinidae	*Lethrinus harak*
	Lethrinus elongatus
	Lethrinus lentjan
	Lethrinus mahsena
	Lethrinus nebulosus
Sparidae	*Acanthopagrus bifasciatus*
Labridae	*Cheilinus mentalis*
	Cheilinus digrammus
	Cheilinus undulatus
	Cheilinus lunulatus
	Cheilinus abudjubbe
	Labroides dimidiatus
	Larabicus quadrilineatus
	Halichoeres hortulanus
	Halichoeres scapularis
	Novaculichthys taeniourus
	Coris gaimard
	Coris variegata
	Hemigymnus fasciatus

	Hemigymnus melapterus
	Anampses twistii
	Thalassoma klunzingeri
	Thalassoma lunare
	Gomphosus caeruleus
Scaridae	*Hipposcarus harid*
	Cetoscarus bicolor
	Bolbometopon muricatum
	Scarus sordidus
	Scarus gibbus
	Scarus ghobban
	Scarus ferrugineus
	Scarus niger
Chaetodontidae	*Chaetodon fasciatus*
	Chaetodon lineolatus
	Chaetodon austriacus
	Chaetodon melapterus *
	Chaetodon mesoleucos
	Chaetodon paucifasciatus
	Chaetodon v pictus *
	Chaetodon lunula **
	Chaetodon semilarvatus
	Chaetodon kleinii ***
	Gonochaetodon larvatus
	Heniochus intermedius
	Heniochus acuminatus **
Pomacanthidae	*Pomacanthus maculosus*
	Pomacanthus imperator
	Pomacanthus asfur
	Pygoplites diacanthus
	Apolemichthys xanthotis
Acanthuridae	*Zebrasoma veliferum*
	Zebrasoma xanthurum
	Acanthurus dussumeri **
	Acanthurus leucosternon **
	Acanthurus nigricans
	Acanthurus sohal
	Acanthurus nigrofuscus
	Acanthurus triostegus ***
	Ctenochaetus striatus
	Naso lituratus

Siganidae	*Siganus rivulatus*
	Siganus argenteus
	Siganus luridus
	Siganus stellatus
Balistidae	*Balistapus undulatus*
	Balistoides viridescens
	Pseudobalistes flavimarginatus
	Pseudobalistes fuscus
	Sufflamen chrysopterus **
	Sufflamen fraenatus **

* restricted to southern Red Sea, Gulf of Aden, Socotra Island Group
** restricted to Gulf of Aden, Socotra Island Group
*** restricted to Socotra Island Group

Species to be recorded in 50 x 1 m transects

Family	Species
Cirrhitidae	*Paracirrhites forsteri*
Pseudochromidae	*Pseudochromis fridmani*
	Pseudochromis flavivertex
Pomacentridae	*Amphiprion bicinctus*
	Dascyllus trimaculatus
	Dascyllus marginatus
	Dascyllus aruanus
	Chromis ternatensis
	Chromis dimidiata
	Chromis caerulea
	Pristotis cyanostigma
	Pomacentrus sulfureus
	Pomacentrus aquilus
	Pomacentrus albicaudata
	Pomacentrus trilineatus
	Stegastes nigricans
	Neopomacentrus xanthurus
	Plectroglyphidodon lacrymatus
	Paraglyphidodon melas
	Chrysiptera unimaculata
	Amblyglyphidodon leucogaster
	Amblyglyphidodon flavilatus

Appendix 6.7.3 Structure of data sheet used to record abundance and length of fishes in detailed surveys and monitoring.

MONITORING FOR REEF FISHES (50 x 5 m transects)

Location: Site: Transect: Date:

Depth: Start time: Vis: Observer:

Species	Number	Species	Number	Species	Number
Cephalopholis		*Labroides dimidiatus*		*Chaetodon*	
		Larabicus quadrilineatus			
		Halichoeres			
Aethaloperca rogaa					
Epinephelus				*Gonochaet. larvatus*	
				Heniochus	
		Novac. taeniourus			
		Coris		*Pomacanthus*	
Plectropomus					
		Hemigymnus		*Pygoplites diacanthus*	
Pseudanthias squamipinnis				*Apolemichthys xanthotis*	
Lutjanus				*Zebrasoma*	
		Anampses twistii			
		Thalassoma		*Acanthurus*	
Macolor niger					
Plectorhinchus					
		Gomphosus caeruleus			
Lethrinus		*Hipposcarus harid*		*Ctenochaetus striatus*	
		Cetoscarus bicolor		*Naso lituratus*	
		Bolbometopon muricatum		*Siganus*	
		Scarus			
Acanthopagrus bifasciatus				*Balistapus undulatus*	
Cheilinus				*Balistoides viridescens*	
				Pseudobalistes	
				Sufflamen	

Numbers of individuals of each species observed are entered into the relevant cell. Blank spaces below genera are used for individual species within that genus. Length (to the nearest centimetre) is estimated for species belonging to the following genera and species: *Cephalopholis, Aethaloperca rogaa, Epinephelus, Plectropomus, Lutjanus, Plectorhinchus, Lethrinus, Hemigymnus,* and *Bolbometopon muricatum*. Numbers of *Pseudanthias squamipinnis* are recorded in abundance categories (see text for details). Length of each individual observed is entered into the relevant cell. Average length is estimated for schooling species such as *Bolbometopon muricatum.*

MONITORING FOR REEF FISHES (50 x 1 m transects)

Location: Site: Transect: Date:

Depth: Start time: Vis: Observer:

Species	**Number**	**Species**	**Number**
Paracirrhites forsteri		*Pristotis cyanostigma*	
		Pomacentrus sulfureus	
Pseudochromis fridmani		*Pomacentrus aquilus*	
Pseudochromis flavivertex		*Pomacentrus albicaudata*	
		Pomacentrus trilineatus	
Amphiprion bicinctus		*Stegastes nigricans*	
Dascyllus trimaculatus		*Neopomacentrus xanthurus*	
Dascyllus marginatus		*Plectroglyphidodon lacrymatus*	
Dascyllus aruanus		*Paraglyphidodon melas*	
Chromis ternatensis		*Chrysiptera unimaculata*	
Chromis dimidiata		*Amblyglyphidodon leucogaster*	
Chromis caerulea		*Amblyglyphidodon flavilatus*	

Appendix 6.7.4 Reef fishes commonly collected for aquaria and recommended for monitoring in the Red Sea and Gulf of Aden region (after EDWARDS 2002).

Family	**Genus**	**Species**	**Common names**
Acanthuridae	*Acanthurus*	*sohal*	Sohal, Red Sea surgeon fish
Acanthuridae	*Naso*	*lituratus*	Orangespine/Lipstick unicorn-fish
Acanthuridae	*Zebrasoma*	*veliferum*	Sailfin tang
Acanthuridae	*Zebrasoma*	*xanthurum*	Yellowtail/Purple tang
Balistidae	*Balistapus*	*undulatus*	Orange-striped/Undulate trigger fish
Balistidae	*Balistoides*	*viridescens*	Titan trigger fish
Balistidae	*Rhinecanthus*	*assasi*	Picasso trigger fish
Chaetodontidae	*Chaetodon*	*auriga*	Threadfin butterfly-fish
Chaetodontidae	*Chaetodon*	*austriacus*	Exquisite/Melon butterfly-fish
Chaetodontidae	*Chaetodon*	*fasciatus*	Red Sea racoon/Striped butterfly-fish
Chaetodontidae	*Chaetodon*	*larvatus*	Orangeface butterfly-fish
Chaetodontidae	*Chaetodon*	*mesoleucos*	Whiteface/Red Sea butterfly-fish
Chaetodontidae	*Chaetodon*	*paucifasciatus*	Redback butterfly-fish
Chaetodontidae	*Chaetodon*	*semilarvatus*	Golden/Redlined/Masked butterfly-fish
Chaetodontidae	*Chaetodon*	*trifascialis*	Chevroned butterfly-fish
Chaetodontidae	*Heniochus*	*intermedius*	Red Sea bannerfish
Cirrhitidae	*Paracirrhites*	*forsteri*	Blackside/Forster's hawkfish
Labridae	*Anampses*	*twistii*	Yellow-breasted wrasse
Labridae	*Bodianus*	*anthioides*	Lyretail hogfish
Labridae	*Cheilinus*	*lunulatus*	Broomtail wrasse
Labridae	*Coris*	*aygula*	Clown/Twin-spot coris/wrasse
Labridae	*Gomphosus*	*caeruleus*	Red Sea bird/Green-bird wrasse
Labridae	*Labroides*	*dimidiatus*	(Bluestreak) Cleaner wrasse
Labridae	*Larabicus*	*quadrilineatus*	Arabian/Four-line cleaner wrasse
Labridae	*Novaculichthys*	*taeniourus*	Rockmover/Dragon wrasse
Labridae	*Paracheilinus*	*octotaenia*	Eight-stripe/Eight-line wrasse
Labridae	*Thalassoma*	*klunzingeri*	Klunzinger's/Rainbow wrasse
Labridae	*Thalassoma*	*lunare*	Moon/Lunare wrasse
Ostraciidae	*Ostracion*	*cubicus*	Yellow boxfish
Pomacanthidae	*Pomacanthus*	*asfur*	Arabian angelfish
Pomacanthidae	*Pomacanthus*	*imperator*	Emperor angelfish
Pomacanthidae	*Pomacanthus*	*maculosus*	Yellow-bar/Bluemoon angelfish
Pomacanthidae	*Pygoplites*	*diacanthus*	Royal/Regal angelfish
Pomacentridae	*Amphiprion*	*bicinctus*	Two-banded anemone fish
Pomacentridae	*Dascyllus*	*aruanus*	Humbug dascyllus
Pomacentridae	*Dascyllus*	*marginatus*	Black-banded dascyllus
Pomacentridae	*Dascyllus*	*trimaculatus*	Three-spot/Domino dascyllus
Pseudochromidae	*Pseudochromis*	*fridmani*	Orchid/Fridman's dottyback
Scorpaenidae	*Pterois*	*miles*	Soldier turkeyfish, lionfish
Scorpaenidae	*Pterois*	*radiata*	Clearfin turkeyfish, Tailbar lionfish
Tetraodontidae	*Arothron*	*diadematus*	Masked puffer
Schooling species			
Pomacentridae	*Chromis*	*viridis*	Blue-green chromis
Serranidae	*Pseudanthias*	*squamipinnis*	Scalefin/Lyretail anthias

Appendix 6.7.5 A selection of fish lengths (cm) useful for training divers to estimate fish length underwater, and the use of a paired t–test to compare a diver's estimate of fish lengths to the actual lengths.

The following table shows fish lengths from a normal distribution with the following parameter values: mean 44.1 cm, standard error 2.58 cm, median 44.5 cm.

7	19	48
9	23	54
12	27	60
16	33	64
22	38	30
26	43	35
32	48	39
36	53	44
42	59	50
47	63	55
52	70	40
57	74	45
62	25	50
68	28	55
73	34	45
80	38	45
85	44	

Use of a paired t–test to test whether a trainee's estimate of the lengths of model fishes is significantly different from their actual lengths; after one trial and after five trials.

Trial 1

Model no.	Rnd no.	Model length	Trainee's estimate	Model no.	Rnd no.	Model length	Trainee's estimate	Model no.	Rnd no.	Model length	Trainee's estimate
1	30	7	5	18	38	19	14	35	55	48	44
2	33	9	8	19	90	23	20	36	91	54	51
3	46	12	11	20	41	27	24	37	37	60	57
4	61	16	13	21	89	33	31	38	40	64	61
5	22	22	19	22	45	38	34	39	81	30	29
6	56	26	22	23	72	43	41	40	77	35	32
7	50	32	31	24	92	48	44	41	18	39	35
8	15	36	34	25	84	53	50	42	75	44	41
9	26	42	38	26	70	59	56	43	85	50	46
10	31	47	44	27	28	63	61	44	13	55	51
11	19	52	50	28	23	70	68	45	67	40	36
12	87	57	55	29	79	74	72	46	34	45	41
13	50	62	63	30	53	25	22	47	56	50	45
14	11	68	66	31	21	28	26	48	64	55	52
15	43	73	70	32	57	34	32	49	56	45	42
16	52	80	77	33	65	38	33	50	83	45	43
17	81	85	80	34	96	44	40				

The trainer observes that the trainee tends to underestimate the length of the model fish, and a paired t–test confirms that the trainee's estimates are significantly different from the actual model lengths (mean of trainee's estimated lengths = 41.2 cm, t = –16.88, P < 0.0001). The trainer informs the trainee of his tendency to underestimate the length of the model fish and the trainee continues his trials. After five trials the trainee obtained the results shown below:

Trial 5

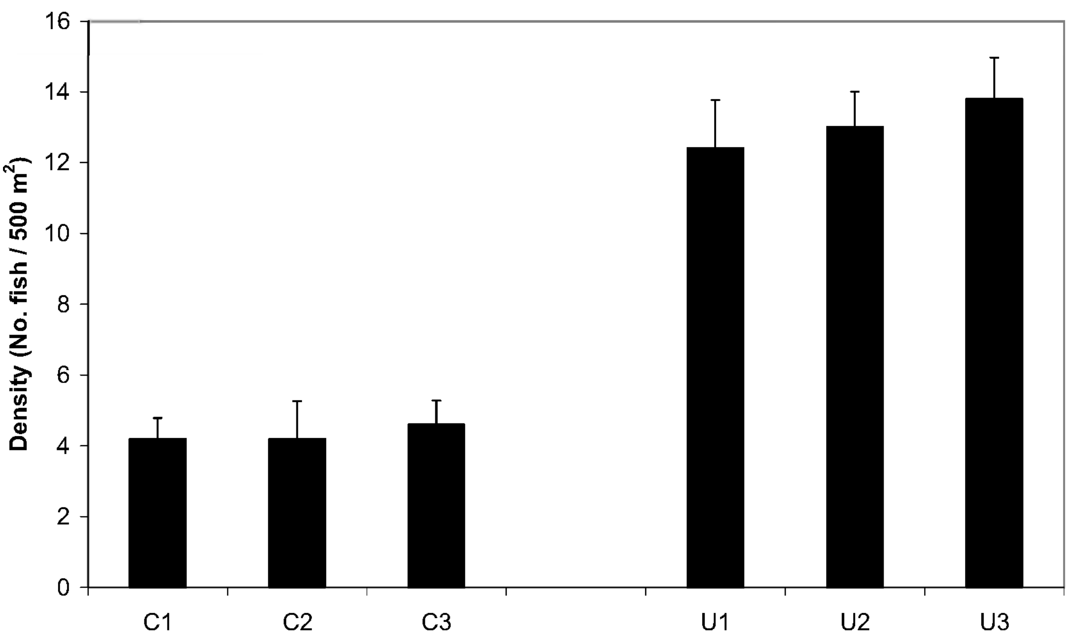
Model No.	Rnd no.	Model length	Trainee's estimate	Model No.	Rnd no.	Model length	Trainee's estimate	Model No.	Rnd no.	Model length	Trainee's estimate
1	30	7	7	18	38	19	19	35	55	48	47
2	33	9	8	19	90	23	23	36	91	54	53
3	46	12	11	20	41	27	26	37	37	60	59
4	61	16	16	21	89	33	34	38	40	64	65
5	22	22	21	22	45	38	38	39	81	30	30
6	56	26	26	23	72	43	44	40	77	35	36
7	50	32	31	24	92	48	48	41	18	39	38
8	15	36	36	25	84	53	54	42	75	44	44
9	26	42	42	26	70	59	59	43	85	50	49
10	31	47	46	27	28	63	63	44	13	55	55
11	19	52	53	28	23	70	69	45	67	40	40
12	87	57	58	29	79	74	73	46	34	45	46
13	50	62	62	30	53	25	24	47	56	50	50
14	11	68	68	31	21	28	29	48	64	55	54
15	43	73	72	32	57	34	34	49	56	45	47
16	52	80	80	33	65	38	37	50	83	45	46
17	81	85	84	34	96	44	44				

After 5 trials the trainee's estimate of the lengths of model fish was not significantly different from the actual model lengths: mean of trainee's estimated lengths = 43.9 cm, t = –1.06, p > 0.25. (Rnd no. = example of a random number assigned to each fish model.)

Paired t–tests can be done with MICROSOFT EXCEL (Data Analysis, t–test: paired two sample for means) and with most commercially available statistical software packages.

Appendix 6.7.6 Hypothetical dataset illustrating the statistical analysis used to test the null hypothesis that activities of aquarium fish collectors had not reduced the overall density of *Acanthurus sohal* in the reef crest habitat.

Treatment	**Collected Reefs**			**Uncollected Reefs**		
Reef (Treatment)	C1	C2	C3	U1	U2	U3
Results	5	5	5	10	16	16
	4	8	4	12	10	17
	3	3	7	9	12	12
	3	3	3	15	14	13
	6	2	4	16	13	11
Mean ±SE	4.2±0.58	4.2±1.07	4.6±0.68	12.4±1.36	13.0±1.0	13.8±1.16

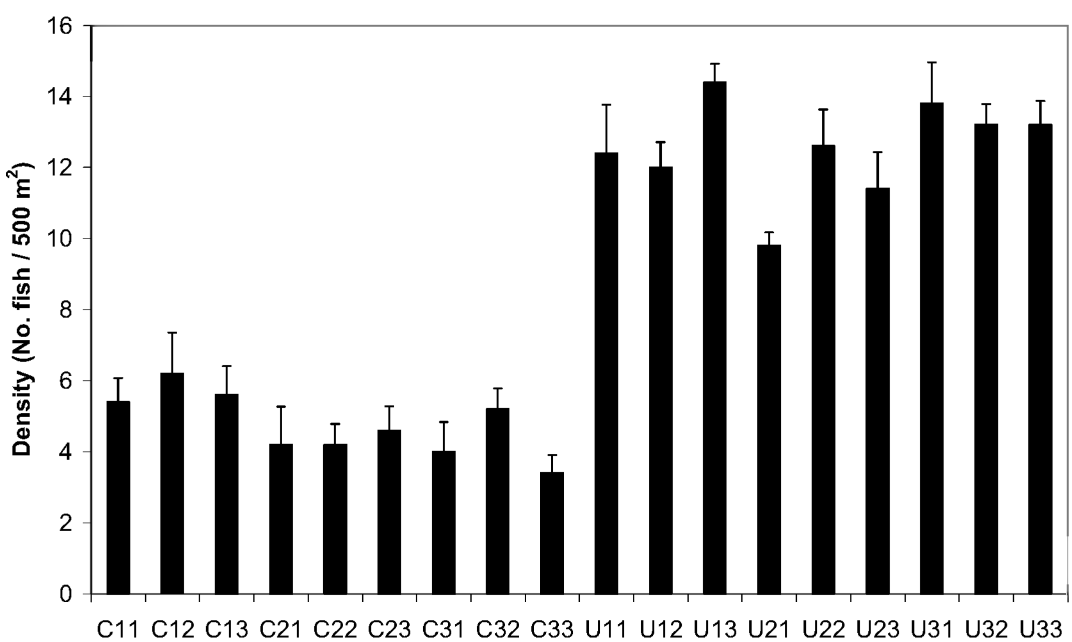


Mean density (± standard error) of *Acanthurus sohal* at three reefs where collecting occurs (C1–C3) and three reefs where no collecting occurs (U1–U3).

Appendix 6.7.7 Hypothetical dataset illustrating the statistical analysis used to test the null hypothesis that activities of aquarium fish collectors had not reduced the density of *Acanthurus sohal* in the reef crest habitat, with three replicate sites sampled in each reef.

Treatment	Collected								
Reef	C1			C2			C3		
Site	C11	C12	C13	C21	C22	C23	C31	C32	C33
Results	6	3	7	5	6	7	2	7	3
	7	4	4	8	4	5	4	5	2
	3	8	8	3	3	4	7	6	5
	5	7	4	3	3	4	3	4	4
	6	9	5	2	5	3	4	4	3
Mean ± SE	5.4±0.6	6.2±1.1	5.6±0.8	4.2±1.0	4.2±0.5	4.6±0.6	4.0±0.8	5.2±0.5	3.4±0.5

Treatment	Uncollected								
Reef	U1			U2			U3		
Site	U11	U12	U13	U21	U22	U23	U31	U32	U33
Results	10	11	14	10	15	10	16	15	13
	12	12	16	10	15	11	17	13	11
	9	10	13	9	12	9	12	14	13
	15	13	15	11	10	15	13	12	14
	16	14	14	9	11	12	11	12	15
Mean ± SE	12.4±1.3	12.0±0.7	14.4±0.5	9.8±0.37	12.6±1.0	11.4±1.0	13.8±1.1	13.2±0.6	13.2±0.7



The graph above shows the mean density (± standard error) of *Acanthurus sohal* per site at three reefs where collecting occurs and three reefs where no collecting occurs. C11: collected reef 1, site 1; U11: uncollected reef 1, site 1, etc.

7

MARINE TURTLES

7.1 INTRODUCTION

Globally, there are seven species of sea turtle: the leatherback *Dermochelys coriacea* (Family Dermochelydae), loggerhead *Caretta caretta*, hawksbill *Eretmochelys imbricata*, olive ridley *Lepidochelys olivacea*, Kemp's ridley *Lepidochelys kempi*, green *Chelonia mydas* and the flatback, *Natator depressus* (all in the Family Cheloniidae). The status of an eighth species, the black turtle *Chelonia agassizii* is currently the subject of debate among biologists, having first been described by BOCOURT (1868) but later disputed by BOWEN et al. (1993). The Convention on International Trade in Endangered Species of Flora and Fauna (CITES) lists all marine turtles on Appendix 1 (prohibited from international trade). The World Conservation Union (IUCN) lists the green, loggerhead and olive ridley as 'Endangered', the leatherback, Kemp's ridley and hawksbill are listed as 'Critically Endangered', and the flatback is listed as data deficient, whereby there is insufficient data to determine its status.

Turtles have been used as a source of food and for other commodities. Trade in turtle products has focused mainly on their carapace, meat, oils and leather. Turtles also provide revenue through tourism, and are important for research, education and employment. Turtles are keystone species, important for the health of the ecological system. Turtles have immeasurable value as cultural assets and can act as flagship species in local and regional conservation projects. To conserve turtles and their habitats, extensive marine areas must be taken under management. This helps protect a range of natural ecosystems and resources in this complex and interconnected world.

The Red Sea and Gulf of Aden (RSGA) region supports five turtle species: the green, hawksbill, loggerhead, olive ridley and leatherback (GASPARETTI et al. 1993). Only the first three are known to nest within the region. The status of marine turtles in the region was summarised by ROSS and BARWANI (1982). This study is still considered one of the most accurate regional reports available.

Green turtle populations were first surveyed in detail in Saudi Arabia in 1986 and 1987 (MILLER 1989). The National Commission for Wildlife Conservation and Development (NCWCD) carried out follow-up surveys from 1989 until 1997 (see AL-MERGHANI et al. 2000 for a review). Green turtles have also been studied in Yemen (HIRTH & CARR 1970; HIRTH et al. 1973), in the Egyptian Red Sea (FRAZIER & SALAS 1984), Oman (ROSS 1984, 1985; SIDDEEK & BALDWIN 1996) and Somalia (SCHLEYER & BALDWIN 1999). Green turtles are herbivorous and spend the majority of their juvenile and adult lives foraging on shallow seagrass beds. Due to the logistics involved with conducting fieldwork at these sites, studies at foraging grounds are limited (HIRTH et al. 1973; ROSS & BARWANI 1982; AL-MERGHANI et al. 2000). Turtles are usually only accessible when the females emerge on beaches to nest. Green turtles normally nest in large aggregations; this makes nesting beach studies particularly useful. Given the long distance migrations undertaken by green turtles, it is possible that nesting females in the region originate from elsewhere (possibly feeding grounds off Oman or Pakistan). In turn, turtles foraging in the RSGA region may migrate elsewhere to nest. This raises international conservation issues that extend beyond the region.

Hawksbill turtles are circumtropically distributed and have been studied in Oman (ROSS 1981), Sudan (ABDEL LATIF 1980; HIRTH & ABDEL LATIF 1980), Yemen (FAO 1973; GREEN 1996), Egypt (FRAZIER & SALAS 1984) and Saudi Arabia (MILLER 1989; PILCHER 1999). Hawksbills inhabit coral reefs where they feed primarily on sponges (MEYLAN 1988). These habitat assemblages are widely distributed throughout the region, making studies of hawksbills at feeding grounds difficult. In the RSGA region, hawksbills tend to nest diffusely on isolated, remote beaches. Hawksbills are believed to make shorter migrations than other species, and may thus remain closer to their natal beaches.

Loggerheads have been studied extensively in Oman, where the world's largest rookery is found (ROSS & BARWANI 1982). More recently, loggerheads have been found to nest in Socotra and Yemen (PILCHER & SAAD 2000). Records exist of migrations of loggerheads from Oman to Socotra and parts of the eastern African continental coastline. Loggerheads forage on a range of hard and soft benthic habitats, primarily feeding on molluscs and crustaceans. As juveniles, loggerheads typically forage in the open pelagic habitats of the Indian Ocean. Given the limited mixing between the Red Sea and the Indian Ocean, it is unlikely that individuals enter through the Bab el Mandeb except as strays. Loggerheads are not common in the Red Sea and probably do not nest there.

Problem	Survey Method	Notes
Need to record and map all areas of concern to turtle populations	Desktop and literature surveys	Provide information on previous studies in the area on which to base further studies
	Preliminary presence-absence surveys	Identify where turtles are found
	Rapid coastal surveys	Identify potential and actual nesting habitats and their characteristics
	Interviews	Provide subjective data on turtle distribution, threats, species presence, etc.
Need to quantify nesting on beaches	Aerial surveys	Provide (limited) but high coverage information on nesting numbers and success
	Detailed nesting beach surveys	Provide accurate nesting volume and success assessments, and options for reproductive biology studies
	Short term nesting beach inspections	Provide rough nesting assessments
	Track counts (short- or long-term)	Provide relatively accurate nesting volume and success assessments and can be rapid
Need to quantify turtle abundance at foraging grounds	Aerial surveys	Provide counts of turtles at the surface for sampled areas, which may be extrapolated to an estimate of total abundance
	Mark and recapture studies	Provide estimates of foraging population size through recaptures of marked individuals. Can be resource and time consuming.
Need to identify individual turtles	Tagging studies	Provide an option for recapture of individuals over time
Need to discover migration destinations	Tagging studies	Based only on recaptures and public participation for tag returns (low cost)
	Satellite tracking	Provide extremely accurate migration path trajectories and destinations (expensive)
Need to determine short-distance movements	Radio or sonic tracking	Provides data on short distance movements of turtles, requires training and experience, can be demanding on financial resources and time
Need to determine reproductive success	Nesting beach surveys	Can evaluate nesting success, egg deposition, incubation period and success, etc.
Need to identify diet of turtles*	Stomach content analysis	Identification of stomach contents requires experience; must be performed by trained personnel
Need to identify reproductive state of turtles*	Laparoscopy	Surgical procedure, requires trained expert and laparoscope
Need to identify impact of fisheries	Observer programmes	Provide data on mortality and accidental captures; can provide additional useful data
Need to determine genetic affiliation of turtles	mtDNA and nDNA analysis	Requires small samples, which can be collected by field researchers; analysis requires laboratory with trained technicians
Need to identify sex ratios of hatchlings*	Histology studies	Requires sacrificing hatchlings for gonad inspection; requires training and experience

Table 7.1 Questions related to marine turtle populations in the RSGA region and suggested survey methods to fill gaps in knowledge. Those marked with a * require significant training and should only be conducted with the assistance of experienced professionals.

Olive ridleys are known to nest in Oman but at no locations in the RSGA region (Ross & Barwani 1982). They are omnivores concentrating on molluscs and crustaceans. It is possible that they forage in Gulf of Aden waters where they may be subject to fishery-related accidental mortality. Olive ridleys share the same developmental habitats and geophysical constraints as loggerheads. They are also not present in significant numbers in the Red Sea.

The leatherback has been documented in northern Red Sea and Gulf of Aden waters. However, is not known to nest in the RSGA region. The leatherback feeds primarily on jellyfish, which are abundant in the Gulf of Aden waters during the monsoonal upwelling season. This is also a period of heavy fishing pressure and the leatherback is threatened by entanglement in fishing gear. Leatherbacks are known to make long migrations and turtles in the RSGA region may originate from the Andaman Islands in India or from South Africa.

Table 7.1 provides an overview of the key questions facing researchers and suitable survey methods for providing answers. These survey methods are based almost entirely on those described in Eckert et al. (1999) and references therein. The following sections provide detailed step-by-step methods for carrying out surveys that will provide adequate data to determine the status of marine turtles in the RSGA region. Each method is preceded by a brief introduction and, where applicable, a description of ways in which the results can be used for management decision making.

7.2 DESKTOP SURVEYS

In a desktop survey, literature should be reviewed to obtain existing information on the region. This will help identify gaps in knowledge and identify where to concentrate future survey efforts. Information will be found in international journals and also as internal reports. Access to a vast literature base is now available through the internet. The main resource is the Sea Turtle list-server called CTURTLE, which one can join by sending a message to <owner–cturtle @LISTS.UFL.EDU> or by following the links on the web pages listed below:

www.seaturtle.org

www.turtles.org.

The Sea Turtle Online Bibliography, maintained by the Archie Carr Centre for Sea Turtle Research (ACCSTR) has thousands of up to date records. Internet access procedures have been improved through the WebLUIS[1] interface and there are now more advanced search capabilities. The Sea Turtle Online Bibliography web site contains access information and links to further information (web page: accstr.ufl.edu/biblio.html).

Maps and charts can often highlight potential nesting areas. For example, mangrove-fringed coasts typically do not support nesting, but island habitats often do. Extensive shallow areas along the coast generally represent shallow muddy substrates unsuitable for nesting. It is important to ground-truth information taken from maps and charts as these are not always at a scale that can reveal specific coastal types.

[1] The WebLUIS interface is being phased out. Access may be made via the University of Florida Database Locator at web.uflib.ufl.edu/locator.html. Search for the 'UF Sea Turtle Bibliography'.

7.3 INTERVIEWS

Interviews should be used when little or no formal reports exist for the area. Interviews should not be restricted to fishermen, because other coastal residents (such as coastguards and ship crews) may have knowledge of turtles in their region. A series of questions about turtles, such as species present, seasonality, egg laying and threats should be posed to obtain basic, unbiased information. The interviewer should carry identification sheets and photographs of different species in and out of the water (see Appendix 7.12.1).

Interviews can take the form of formal questionnaires with a pre-prepared list of questions. However in the RSGA region, simple discussions with the local residents have proven more useful. It is important to keep in mind the basic questions for which answers are sought, but informal discussions often reveal more accurate information. When asking questions it is important that the interviewee feels relaxed and is not intimidated, for instance when asking questions on exploitation. Questions that must be incorporated into informal discussions are:

- Do you see turtles nesting/swimming around here?
- If so, where do you see them?
- Are they all the same kind, or do you see different types of turtles?
- What names do the turtles have?
- Do they look like any of the ones on these graphics/photographs?
- Can you match your turtle names with the pictures?
- Is there any particular time of the year that you see turtles?
- When was the last time you saw them?
- Do they nest in large numbers, or just a few at a time?
- Do you see more than ten in one night?
- Where are the beaches where you see the turtles?
- Could you show us the beaches where you see them?
- Do people eat turtles? What about their eggs?
- Are turtles used for anything else?
- Have the numbers of turtles increased over the years?
- Do you think there is anything that might be killing turtles and reducing their numbers?
- How would you feel about helping to protect sea turtles?

7.4 PRELIMINARY SURVEYS

Long-term conservation of sea turtles depends on the availability of suitable nesting beaches. Therefore, it is useful to determine the location of nesting habitats and the size of nesting populations. Records need to be gathered on habitat area and type, ownership and conservation status, along with notes on anthropogenic and natural threats. The existence of many kilometres of sandy beach does not guarantee the existence or suitability of nesting habitat. One must first identify potential sites through literature searches and interviews, and then carry out surveys by boat or airplane. Whichever method is used, surveys must be cost-effective, reproducible, quantitatively rigorous and easily taught to others.

7.4.1 Preliminary nesting beach surveys on the ground

These are possibly the most widely used type of survey because turtles emerge onto land to nest and can then be easily studied. Surveys over several seasons can give an indication of trends in the size of nesting populations, which may be correlated loosely with overall population sizes. Ground surveys are used when the beach is accessible and relatively short, or if there is a need to study the nests themselves (e.g. for nesting success). They are also used when air surveys are unsuitable, for example due to obstructions, or when crawls (tracks) cannot be identified from the air (such as on rocky or pebble beaches, as on Socotra). Surveys can occur over the long-term and be highly structured, or can be rapid 'snapshots' of the current situation.

Ground surveys cover the coastline looking for signs of nesting. The most obvious signs to look for are the presence of tracks, but other information can also be collected. For example, the species of turtle can often be determined by the size and type of the tracks. Hawksbills are small and walk with an alternating gait leaving narrow asymmetrical tracks; greens are large and walk with a simultaneous gait, leaving wide, symmetrical tracks. Similarly, the success of the nesting attempt can often be determined by looking at the nesting pit. Predominant threats should be noted, as well as ownership of the site. Normally patrols are carried out on foot. When the area is large, one can use four wheel drive 'All Terrain Vehicles' (ATVs) for patrolling the beach. ATVs have large, balloon-type tyres that prevent getting stuck in the sand. These specialist tyres do not damage eggs incubating in the sand if a nest is accidentally driven over. The researcher should be equipped with predesigned data sheets, pencils and camera. Survey methodology is outlined below:

- Define the survey area.
- Partition into smaller sub-units, no longer than 1 km (use long-lasting markers, or take bearings on permanent structures, or use GPS).
- Carry out patrols shortly after sunrise, when tracks are still fresh (the sun dries the sand and tracks become obscured).
- If other beach survey efforts are underway, track counts can be done at night, although one runs the risk of disturbing nesting turtles.
- Move along the latest high tide line.
- Record the number and type of crawls, nesting pits, eggshells and slaughtered turtles.
- Distinguish between fresh crawls (those returning through the previous night's tide line) and old crawls. This allows a count of the number of turtles nesting the night before, and the total over the last few days. Driving the length of the beach the day before the crawl count 'marks' all existing tracks. Only tracks that cross the vehicle tracks will be 'fresh' on a subsequent count.
- Identify direction sand is pushed and thus direction of crawl.
- Follow emerging crawl and look for loose sand covering the crawl.
- Look for loose sand 'plume' from filling-in process (sometimes more damp than surface sand) and for a secondary body pit.
- Determine if the emergence resulted in successful nesting. Also record the number of unsuccessful pits (if any) the turtle excavated. False crawls tend to have unfinished primary pits, often with a partially excavated egg chamber. Note possible signs of

disturbance. Frequently the turtle makes a number of unsuccessful body pits before returning, or before finally nesting successfully. Note: it is important on high density nesting beaches to be careful when following the tracks of turtles that have attempted to nest, moved a few metres, and attempted to nest again, as tracks can easily get confused.

- Check the length of the crawl (if return is a lot longer than emergence, it is probable that the turtle spent a long time on the beach and there is a good chance she nested. Caution: she might only have been wandering or digging unsuccessfully).
- If predators have excavated nests, they should be marked as successful nests, with an additional comment on predation (as the turtle did indeed lay eggs).
- When nesting success is not certain, mark nesting success as unknown.
- Mark each track after it is recorded by scraping a line through it with a stick. This will avoid duplicate counts of the same track.
- Determine the species by track type.
- Use results from the counts to determine the number and density of turtles nesting in each area. Over the course of several seasons, these data can also provide an understanding of inter-seasonal fluctuations.
- Record the following beach characteristics:
    - Location (GPS)
    - Vegetation type
    - Beach length
    - Beach width
    - Beach slope
    - Beach composition (grain size, type, compaction)
    - Wave conditions and patterns
    - Presence/absence of rivers
    - Presence/absence of man-made structures
    - Potential threats

7.4.2 Preliminary beach patrols by aircraft

Aerial surveys are typically used for large areas. Helicopters are the best option as they can hover and fly at slow speeds. However, they are more expensive and not always available. Single engine, wing above cockpit, aircraft are the most widely used for aerial surveys. Typical methodology is as follows:

- Determine survey area.
- Keep speed in the range of 80–100 knots (it is hard to count tracks at any higher speed).
- Keep altitude between 50 and 300 m (the greater the altitude, the larger the field of view, but the less discernible lighter tracks are, such as hawksbill or olive ridley; optimal altitude should be around 150 m).
- Aircraft must maintain constant speed, height and relative position to the shore while maintaining safety.
- Position the aircraft so that the observer can see the beach clearly. Usually this can be done by keeping the craft 0–20 m offshore, where the observer can see tracks emerging and returning to determine nesting success.
- Keep all surveys less than two to three hours in duration to avoid fatigue.

- Have two or more observers who do not communicate their results during the flight to test for observer differences / errors / biases. Observers should be well trained and highly experienced in identifying the characteristics and types of nesting crawls and nesting marks.
- Carry out surveys at dawn, when shadows on the tracks are most visible.
- Schedule flights on the mornings before, on, and after the day when spring tides peak after about 1900 to 2000 hours (this way the tide will be 'in' during the night, and then 'out' for most of the early morning and during the surveys, and data can be averaged for the three-day results).
- Search for tracks that extend below the latest high tide line.
- Determine nesting success and species.
- Mark nests as successful, unsuccessful or unknown.

7.4.3 Ground-truthing

The accuracy of counts from aircraft, or those conducted by trainee researchers, must be ascertained in order to achieve acceptable results. Factors affecting accuracy include:

- *Observer accuracy*. For instance, each observer may record different numbers of crawls, or misidentify the species.
- *Turtle species*. Hawksbills are lighter, and leave a much 'shallower' track, also they tend to nest close to vegetation and pits might not be visible.
- *Nesting density*. High-density beaches are not good for aerial surveys, as the observers tend to get confused counting tracks that overlap.
- *Beach type*. Grain coarseness can affect the impressions made by turtles during the crawl.
- *Time of day*. The angle of the sun might make it hard to see tracks if there are no shadows.
- *Weather*. Wind and rainfall might erode tracks away.
- *Human activities*. These may obscure tracks and pits.

Therefore, aerial surveys in particular require ground-truthing. This involves comparing data collected by aerial observers or other beach monitoring efforts with data collected by an experienced researcher on the ground. This can be established through the presence/absence of eggs on studied beaches.

- Identify beaches where nesting was thought to have occurred.
- Locate what are thought to be successful nests.
- Dig gently by hand a small hole in the area that is thought to contain eggs.
- When reaching nearly one arm's length, continue slowly and carefully.
- When eggs are encountered immediately re-cover the nest and mark it.
- Identify differences between ground-truth data and aerial survey / trainee field data. Errors between both data sets then yield an error factor, which must be considered in all subsequent estimates.

7.4.4 Preliminary foraging area surveys

Sea turtles spend most of their lives in the water, such as in coral reef and seagrass habitats. The number of studies that can be carried out in these habitats is significantly reduced because of the logistics involved, costs, etc. Potential foraging areas should be visited using snorkel or scuba equipment. Survey methodology is outlined below:

- Record the presence of foraging turtles.
- Record area location (GPS), relevant underwater life forms (seagrasses, sponges) and physical characteristics (currents, depth, water temperature, benthic structure).
- Turtle densities should be established using line transects and quadrat methodology (see chapters on Rapid Assessment and Corals and Coral Communities).
- Capture turtles using nets or rodeo-style captures (see below).
- Use mark and recapture studies (see below) to provide information on abundance, distribution, size classes and species.

7.5 AERIAL SURVEYS

Aerial surveys are generally expensive, but provide extremely wide area coverage in a very short time. Often, when the costs of mounting large-scale ground projects are compared with two or three days of aerial surveys, the latter is found to be the most cost effective. Surveys can be done from a small airplane or by helicopter, the latter having the option of landing at selected sites for closer inspection. Airplane surveys are fast and can cover a large area without landing. Helicopters need to refuel more often and thus have shorter flight ranges. Whichever is used, flight attitude and altitude should be maintained constant to allow standardisation of observations.

7.5.1 Aerial surveys of nesting beaches

When surveying nesting beaches, it is useful to have maps or charts for the area to be surveyed prepared in advance. Photocopy maps into manageable A4 or A3 size and stack these in sequential order. As the aircraft flies along the coast, keep track at all times of the location by referring to major landmarks on the charts, flipping to the next chart as land area is covered.

7.5.2 Aerial surveys of foraging grounds

These methods work because turtles surface to breathe, at which point they can be counted during strictly timed ‘passes’ or transects. Turtles are counted and where possible, species identified. The number of sightings in a set area (the sample) can then be extrapolated to cover wider areas to arrive at an overall area estimate (the population). Due to the difficulties in observing turtles and identifying species, surveys must use trained observers. The aircraft (single engine for nearshore, twin engine for offshore) should have easy line-of-sight to the sea surface, through Plexiglas windows in the nose or floor or protruding bubbles. Planes should be equipped with a GPS navigation system. Transect (flight line) length should be determined after taking into consideration the area to be surveyed, time available, and overall objectives. The best results are obtained when more than 30 turtles are identified. In conjunction with field studies, which determine the average proportion of time spent at the surface for the species in question, the results of these surveys can be extrapolated to include turtles that may have been submerged during flight overpasses.

Aircraft preparation

Mark aircraft windows to provide a field of view in order to survey the area quantitatively. This will establish a sector through which the viewer should focus attention. The sector should be of a known width.

- Carry out a test flight at the predetermined altitude (e.g. 150 m) in a straight line as close as possible to a known long reference line (such as a straight road), so that the observer can see the reference line straight below the aircraft (Figure 7.1a).
- Mark the window with a greaseproof pencil where the reference line is seen, to identify the inner boundary of the survey zone.
- Have the pilot move perpendicularly away to the limit of the observer's field of view through the window and determine the straight-line distance from the reference line (using the aircraft's GPS) (Figure 7.1b).
- Mark the window with a greaseproof pencil where the reference line is again seen, to identify the outer boundary of the survey zone.
- Repeat for the other side of the aircraft.

The total area covered by each flight transect (A) can then be calculated using:

$$A = wL$$

where:

w = the width of the viewing area (equal to the perpendicular distance away from the reference line) and

L = the length of the individual transect.

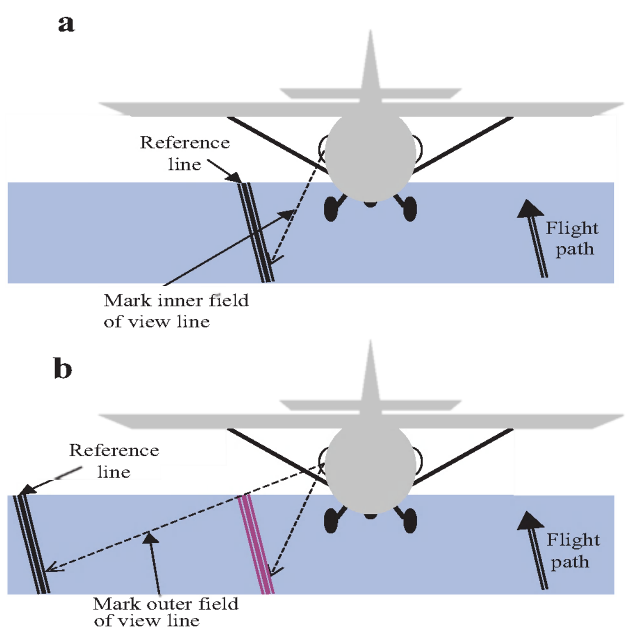


Figure 7.1 Aircraft setup: a – fly along reference line and mark proximal survey area limit on window;
b – move horizontally away to distant limit of the field of view and mark outer limit of survey area.

Survey flight methods

- Transects should be parallel to each other, and perpendicular to the depth contours.
- Flights should be planned with safety in mind and carried out in calm weather (Beaufort Sea State ≤ 2), as turtles are difficult or impossible to spot in rough sea conditions.
- Flights should be conducted close to noon (12:00 hours) to minimise glare.
- Have one observer on each side of the aircraft.
- Where possible, have one additional observer in a front seat taking independent recordings, to check against the rear observer.
- Observers should attempt to identify the species based on silhouette (see Appendix 7.12.1), or at least identify between hard shelled and leatherback.
- Keep all surveys to less than 2–3 hours to avoid fatigue.
- Record number and species (where possible) of turtles in each transect.
- From transect surveys, compute a population estimate (C) using:

$$C = (n / 2\, wlg)\, A$$

where:

n = number of turtles counted

l = length of transects

w = width of transects

g = fraction of turtle population visible

A = size of study area (from above).

7.5.3 Additional data collection

During aerial surveys of open water habitats, data on other marine animals can be collected, given the low density at which these and turtles are encountered. Therefore, aerial surveys can be used to determine the distribution and abundance of turtles, whales, dolphins and dugongs all in the same project (see chapter on Marine Mammals).

7.6 NESTING SEASON SURVEYS

Estimating population numbers is useful in conservation programmes to help understand long-term trends in population size and the severity of threats (small populations are in more danger than larger ones). One can count absolute numbers (e.g. total number of females) or relative numbers (e.g. number of nesting females or number of nests). One can also count emergence tracks to determine relative nesting population sizes. In all cases one must consider *bias* (measured as closeness to actual figure) and *precision* (measured by the variance). For example, aerial surveys are imprecise and biased (turtles are rare and the results are always underestimated), while comprehensive nest counts are precise and unbiased (one can count each nest and the results among different researchers would nearly always be the same).

An understanding of reproduction and nest biology is a valuable tool for conservation and management of sea turtle stocks. Without this knowledge, well intentioned, but ignorant, conservation efforts can be detrimental to sea turtles. The nesting beach provides a narrow but important window for studying sea turtles.

When studying nesting populations, one needs to bear in mind that the number of nesting turtles varies annually, often to extremes. For example, at Ras Baridi on the Saudi Arabian Red Sea coast, nesting numbers have fluctuated from 110 individuals one year to only 17 the next, and back up to 73 the following year. This is a normal occurrence and is used to highlight the need for long-term studies (decades) at nesting beaches to determine any trend in population size. If one were to record the numbers of turtles during a 'bad' year, this would give a false underestimate of the average nesting numbers, while similar work during a 'good' year might yield a false overestimate. In addition, marine turtles do not nest every year (typically there is a three to five year interval). Thus, understanding annual variation in numbers of nesting females requires comprehensive beach coverage for most of the nesting season and monitoring surveys that extend over several years. While one-season nesting surveys cannot provide reliable data on population size, they can give useful information on female nesting biology and overall reproductive output, as well as threats and conservation needs. Additionally, they provide a useful platform on which to base public awareness and beach conservation projects.

7.6.1 Survey timing and duration

Surveys should be timed so that they start at or near the beginning of the nesting season. This can be determined from earlier interviews, nesting at nearby sites or through previous reports. Turtles are generally nocturnal, although they do occasionally nest during the day. Beach surveys should be carried out at night, starting from shortly after sunset until no further turtles are encountered on the beach. Periodic but less frequent surveys should also be carried out during the day to detect daytime nesting activity. Lights should be restricted to small penlights or flashlights, preferably with a red filter, and movements by personnel in the vicinity of turtles should be slow and deliberate, as turtles are sensitive to light and movement.

Long-term comprehensive nesting surveys

These surveys target nesting beaches with significant breeding populations, or beaches that host the only known nesting population. They are time and labour intensive and require a significant degree of planning and logistical arrangement. At night researchers should monitor all or parts of the nesting site and collect data on nesting numbers, turtle morphometrics (size measurements, weight), damage to turtles, number of eggs laid, nest location and a number of other variables. During the day data can be collected on turtles not sighted during the night surveys, beach area and morphology, sand characteristics, males (by rodeo capture), and inter-nesting habitats (see methods below).

Peak nesting season surveys

To minimise survey effort, it is often possible to concentrate studies on turtles during the three to four weeks at the peak of the nesting season. This can only be done when a substantial amount is known about the nesting populations, as in Saudi Arabia. For instance, knowing that green turtles nest on Karan (Arabian Gulf) from May to September, with a peak in July, allows researchers to target this month rather than spend four months on the island. During this time up to 80% or 90% of the nesting population can be encountered.

7.6.2 Location information

- Standardise the nesting location name. Location can be further subdivided into sites (for instance, an entire island may constitute a location, while the North, East, West and South might constitute sites).

- Identify individual beaches, and subdivide beaches by sectors (where the beaches are longer than 1 km).

7.6.3 Nest characteristics

- Record the exact nest location (useful for returning to the same nest at the end of the incubation period to determine incubation success). The particulars of each nest allow a comparison among populations and can provide a descriptive summary of the physical characteristics of nests.
- Measure nest depth from the top of the sand (average beach surface) to the bottom of the egg chamber and also to the top of the uppermost egg. Take measurements using a flexible fibreglass tape measure (±1 mm) as the turtle completes the chambering process and then again after the last egg is deposited, but before filling-in commences.
- Attach an identification marker to a 1 m piece of coloured tape.
- Insert the tape and tag plate as the turtle deposits the eggs.
- Record an individual nest identification number on the marker, in permanent ink.
- Maintain a database of nest data, to include the following information: tag number; date and time laid; nest depth (top and bottom); nest location (according to sector code or triangulation coordinates – see below); nest habitat type (open beach, vegetated beach, etc.); sand temperature; clutch count; egg diameter and egg weight.
- Cross-reference the nest number to the tagging data for the female that deposited the eggs.

The tag can be recovered easily when the nest is excavated, by searching for the coloured tape. Where egg poaching is common, nest locations must be recorded without allowing for detection. This can be done by measuring distances and angles (transits) to at least two nearby immobile objects such as large rocks, trees or headlands.

- Draw a diagram showing the approximate location of the nest.
- Measure carefully and record the distance from the nest to one of the reference points using a long tape measure. Measurements must be accurate as the beach may change shape through erosion and other nesting activity over the next 60 days.
- Repeat for the second and subsequent reference points.
- When relocating the nest, attach the tape measure to the first reference point, then extend it to the distance recorded earlier in the general direction of the nest and mark an arc in the sand.
- Repeat the procedure for the second and subsequent measurements from reference points.
- Relocate the nest by finding the point at which the measured transits cross (Figure 7.2).

7.6.4 Nesting turtles

Generally only female turtles emerge onto nesting beaches, although sometimes males emerge while still in a copulating position mounted on the female. Consequently much more information has been collected for female turtles than for males. Adults are measured to provide an indication of general population characteristics, to determine the minimum size at maturity and for subsequent re-measurement at later dates to enable calculations of growth rates. They are usually tagged to provide individual recognition in subsequent recaptures and to prevent re-sampling of the same individual. Female turtles can be identified using the diagrams in Appendix 7.12.1.

7.6.5 Morphological data

Turtles are measured on nesting beaches to relate body size to reproductive output, at foraging grounds to determine frequency of size classes (to determine demographic structure), and to monitor growth rates (in subsequent recaptures). It is important to ensure accurate measurements are taken and recorded. Practice measurements can be made on a turtle carcass or a sample turtle. The sample size should also always be reported so that one can determine the validity of the summary data. An average taken among four individuals will not be as precise as an average taken from 100 individuals. It is best to have one researcher take all measurements all the time to ensure consistency in methodology. If this is not practical, different researchers should practice and standardise methods prior to actual data collection. Consistency in measurement taking is critical for later comparisons and analysis. Curved measurements are taken over the curve of the carapace with a fibreglass tape measure (± 0.1 mm). Straight length measurements are taken with callipers (± 0.1 mm) to record the straight-line distance between one point and another. The arms of the callipers should only be as long as necessary, to reduce bulk and to increase accuracy. The length should only be slightly larger than the maximum expected size and all records should be able to be taken in a single attempt, rather than several partial measurements. Any barnacles or other organisms growing where measurements are to be taken should be removed with pliers beforehand. A sample data sheet for recording nesting data is presented in Appendix 7.12.2. The following are the most common measurements recorded for sea turtles.

- Curved Carapace Length (CCL) – measured over the curve of the carapace along the midline from the anterior point at the midline of the nuchal scute to the posterior tip of the surpacaudal scutes (Figure 7.3).
- Curved Carapace Width (CCW) – measured over the curve of the carapace perpendicular to the midline across the widest portion of the carapace (Figure 7.4).
- Straight Carapace Length (SCL) – measured as a straight-line distance

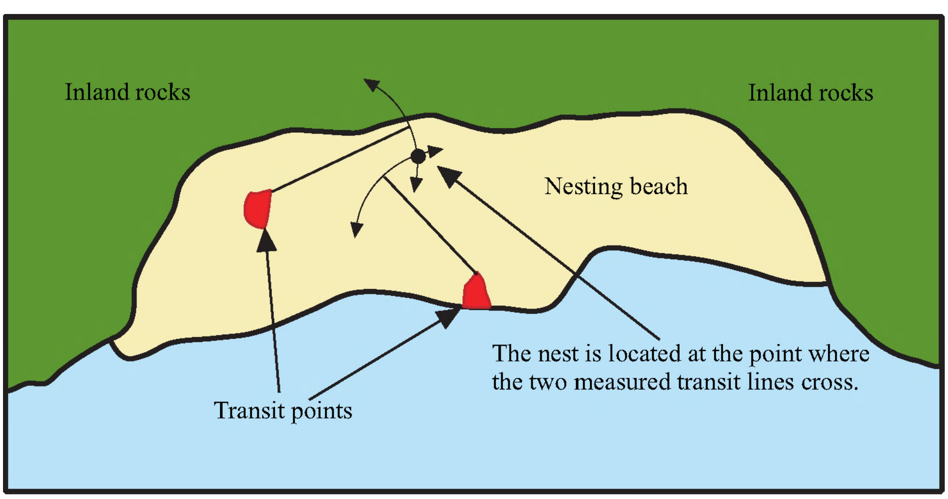


Figure 7.2 Nest relocation technique using permanent transit points

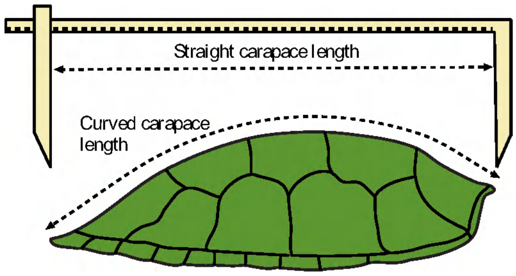


Figure 7.3 Curved and straight carapace length measurements

between the anterior point at the midline of the nuchal scute to the posterior tip of the surpacaudal scute (Figure 7.3).

- Straight Carapace Width (SCW) – measured as a straight-line distance between the outer edges of the marginal scutes at the widest portion of the carapace perpendicular to the midline (Figure 7.4).
- Plastron Length (PL) – measured along the midline from the joining of the skin and plastron at the anterior edge to the posterior-most projection of the bone. If the turtle is not turned over for weighing, this length need not be taken (Figure 7.5).
- Plastron Width (PW) – measured across the plastron at its widest point perpendicular to the length. If the turtle is not turned over for weighing, this measure need not be taken (Figure 7.5).
- Head Width (HW) – a straight distance across the widest portion of the skull. Care should be taken when taking this measurement as the turtle's ears are hidden behind the large lateral scales posterior to the eyes.
- Tail Length (TL) – measured from the tip of the tail to the trailing edge of the plastron (Figure 7.6a) and from the tip of the tail to the cloaca (Figure 7.6b).

For leatherbacks, curved measurements are not taken on the top of the carapace ridges due to shape irregularities. The curved measurement is taken as in the case of hard-shelled turtles, but the tape is allowed to run along one side of the dorsal ridge. Curved width is recorded from side to side over the tops of the ridges, at the widest point. Straight length is measured from the anterior edge of the carapace at the midline to the furthest point on the caudal peduncle. Plastron measurements are not practical and are therefore not taken.

7.6.6 Weight

Turtles should be weighed with a saltwater-resistant spring balance (±0.5 kg). The easiest way to weigh turtles is to form a figure of eight with a sturdy piece of rope measuring about 2 m in length. One end of the loop should be slightly larger than the other and the cross point should be tied tight. After carefully flipping a turtle onto its back, the smaller loop can be placed over the front flippers and head to support the anterior portion of the carapace. The larger loop is looped over the rear flippers and tail and supports the posterior of the carapace. A balance is positioned at the cross point and supported with a sturdy brace, which is then lifted by two people (Figure 7.7).

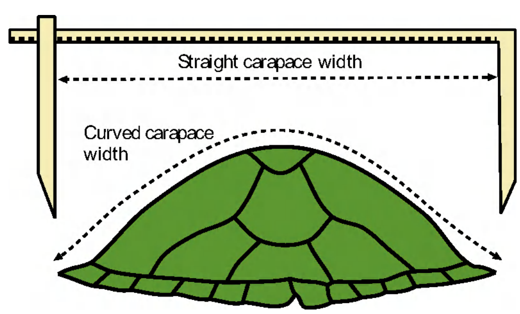


Figure 7.4 Curved and straight carapace width measurements

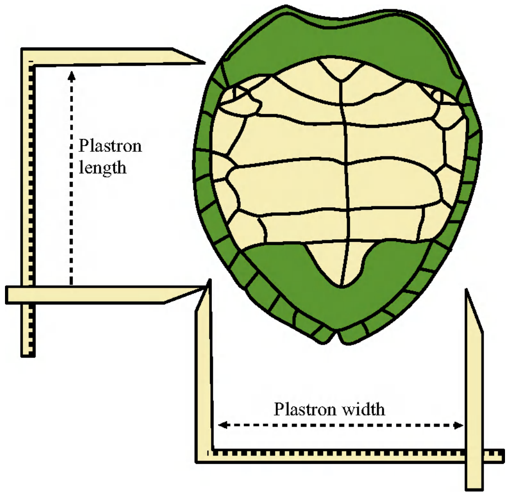


Figure 7.5 Plastron length and width measurements

During initial surveys it is suggested that as many turtles as possible be weighed. Not all turtles need to be weighed during subsequent surveys; a sample of 10–20% of the population will provide a suitable estimate.

Morphometric data are used to compare populations from different years and different locations, both regionally and globally.

- Summarise data from each nest for each site.
- Present morphometric and weight data as averages (x) for the whole sample, noting the range (minimum and maximum), standard deviation (SD) and sample size (n) (using a suitable spreadsheet programme).
- Present morphometric data in tabular form (see example presented in Table 7.2 below).
- Use morphometric date to describe the basic parameters of the population.

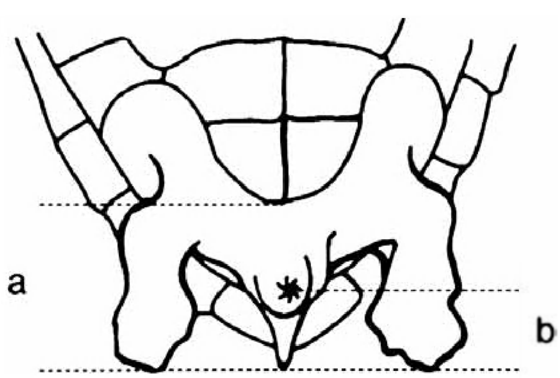


Figure 7.6 Tail measurements

Long-term data sets can be used to monitor recapture rates of previously tagged turtles, which can be indicative of tag-loss rate. An example of the manner in which this is presented is shown in Table 7.3. A consistently low recapture rate may suggest overfishing and exploitation if recaptures are constantly low (such as the example in Table 7.3).

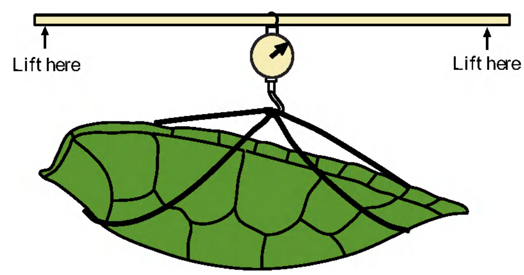


Figure 7.7 Weighing a turtle

7.6.7 Tagging

Tagging turtles is a useful research tool but is not a necessity for nesting beach studies. If the objective is simply to count turtles, short-term recognition can be achieved using spray paint to mark the carapace. This typically lasts about two weeks in the natural environment. For a tagging programme to be effective there must be a commitment to future surveys and tag returns. Tags, if used, should conform to the following characteristics:

- Tags should be made of titanium (this metal has shown some of the greatest resistance to corrosion, and is among the longest lasting underwater) and can be purchased from Stockbrands Pty (Fax 69–9–444–0619).
- Numbers should be consecutive and prefixed by the country's international ISO code.
- Researchers are responsible for ensuring that tag numbers are not duplicated within a project or among projects.
- Half the tags should bear the message "Notify PERSGA PO Box 53662 Jeddah 21583 KSA" in English, the other half should bear the same message in Arabic. Apply one of each to each turtle.
- Do not order double sets of tags (i.e. bearing the same number), or attempt to tag a turtle with the same number on each flipper (this is unnecessary and increases the risk of two turtles accidentally being tagged with the same number).

Tagging should follow the methods outlined below:

- Practice with several tags on a piece of cardboard prior to working with turtles.
- Mark one side of the applicator with paint to identify the top position.
- Tape tags together on their cardboard sleeves to reduce tag loss and maintain tag order.
- Check turtles for presence of previous tags or signs of tag loss prior to placing new tags, and keep notes.
- Replace old tags only if they appear heavily corroded and might be lost easily.
- Record all previous tags to maintain a long-term history of the turtle.
- Turtles that show signs of having been tagged previously but which have lost their tags should also be recorded as such, as this provides information on the rate of tag loss.
- Tag new turtles on the proximal trailing edge of each front flipper (Figure 7.8) to reduce the chances of abrasion, entanglement and tag dislocation.
- Tagging is a two-step process:
    - clamp applicator so that the sharp point pierces the flipper and
    - apply greater force to ensure the tag point bends over and securely locks into rear of tag.

	CCL	*CCW*	*SCL*	*SCW*	*PL*	*PW*	*HW*	*TL*	*WGT*
X	94.30	85.80	86.30	69.10	75.00	65.50	17.50	15.70	94.50
SD	4.26	3.27	5.16	2.53	9.09	10.09	1.64	2.71	6.52
Max	103.00	93.00	91.00	73.50	91.50	89.00	21.00	21.00	108.00
Min	79.00	79.00	70.00	64.00	62.00	6.00	12.50	10.50	84.00
N	49.00	49.00	15.00	15.00	49.00	49.00	49.00	49.00	11.00

Table 7.2 Morphometric summary of adult loggerhead turtles in Socotra. x = Average; SD = Standard Deviation: n = Sample size; CCL = Curved Carapace Length; CCW = Curved Carapace Width; SCL = Straight Carapace Length; SCW = Straight Carapace Width; PL = Plastron Length; PW = Plastron Width; TL = Tail Length; HW = Head Width (all in cm); WGT = Weight (kg).

Season	Arabian Gulf						Ras Baridi		
	Chelonia mydas			*Eretmochelys imbricata*			*Chelonia mydas*		
	New	Recap	Total	New	Recap	Total	New	Recap	Total
1986	1124	—	1124	15	—	15	—	—	—
1987	330	0	330	20	0	20	15	—	15
1988	—	—	—	—	—	—	—	—	—
1989	—	—	—	—	—	—	61	0	61
1990	—	—	—	—	—	—	16	1	17
1991	894	0	894	145	0	145	95	11	106
1992	512	18	530	123	4	127	19	15	34
1993	999	29	1028	34	3	37	27	8	35
1994	378	60	438	39	16	55	20	14	34
1995	346	85	431	34	21	55	13	7	20
1996	—	—	—	31	17	48	—	—	—
1997	201	56	257	32	20	52	—	—	—
Total	4784	248	5032	473	81	554	266	56	322

Table 7.3 Suggested layout of tagging records over time.

- Check carefully to ensure the tag is securely attached, and that the sharp point of the tag has looped through the receiving hole and curved into a locking position (it is possible that the sharp point curves back under the receiving side of the tag, or outside of it).
- Leave a 0.5–1.0 cm gap between the trailing edge of the flipper and the rear edge of the tag when tags are applied to adult turtles (Figure 7.8).
- Leave a 1.0 cm gap between the trailing edge of the flipper and the rear edge of the tag when tags are applied to juveniles.
- Only tag turtles when they have completed covering the nest cavity with the rear flippers to minimise the possibility of disturbing the turtle, causing her to abandon the nesting effort.
- Tag turtles that emerge but fail to nest when they are returning to the sea, as they will usually return to nest at a later time or date.
- Tag number and placement (i.e. which flipper) should only be recorded after tagging has been completed successfully. Tags can break on application and must be discarded, and it is possible to forget to change the number if it is pre-recorded. Only the tag that is actually placed on the turtle should be recorded.
- Copies of the tagging records should be submitted to PERSGA by the researcher at the conclusion of each research period, to maintain an up-to-date database of tagged turtles in the RSGA region.

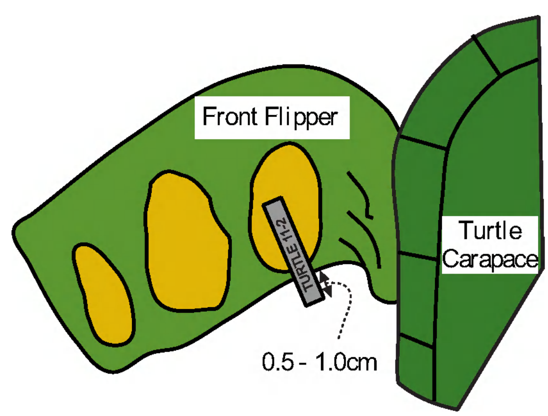


Figure 7.8 Tag position and gap between outer edge of the tag and the trailing edge of the flipper

7.6.8 Determining clutch size

Clutch size is typically determined at oviposition but if the nest has to be moved, eggs can be counted at that time. Clutch size should be determined for a minimum of 10% of the nesting population. It is useful to have a mechanical counter, which is pressed each time eggs are deposited, because it is easy to miscount the number, and practically impossible to recount without excavating the nest after the female returns to the sea. The clutch size is defined as the number of normal eggs and extra large eggs (as these may contain multiple embryos) laid into the nest. Any turtle that lays a second clutch within six days of the first was disturbed in the earlier attempt, and the two partial clutches should be added together to obtain the actual clutch size for that instance, provided the turtle was marked and can be identified.

- Observe the female and wait until the chambering process is nearly complete.
- Slowly crawl up behind the female, and wait until egg deposition begins (determining this takes an experienced researcher, but generally occurs when the female ceases the chambering actions of the rear flippers, and draws the rear flippers inward in a protective manner over the nest cavity).
- Shine a small flashlight directly into the nest cavity at close quarters, careful to avoid disturbing the nesting female.
- Count the number of normal eggs (normal shape and size, white, spherical, and which have a yellowish hue when a flashlight is shone through) and odd-shaped eggs (these are small or extra large, or of different shape when compared with normal eggs, and have a white hue when a flashlight is shone through).

7.6.9 Measuring and weighing eggs

Eggs should be handled with caution and only when necessary. Once a sample has been obtained, measured and weighed, quickly return the eggs to the nest before completion of oviposition. Handle all eggs carefully with clean hands, *without rotation* and only within two hours of when they were laid. Any movement of eggs from this time for the next 25 days results in movement-induced mortality of the embryos. Therefore, if the clutch will be affected by tides and needs to be moved, this should be done within two hours. The clutch should be moved to a location with suitable 'nesting beach' characteristics, with regard to temperature, shade, moisture, etc.

- Clear a flat space close to the chamber and line with a plastic bag.
- Collect ten eggs at random as the female deposits the eggs into the nest chamber, by digging a narrow tunnel through which the arm can be extended, and place them on the plastic bag.
- Clean the eggs of any adhering sand.
- Press gently on the egg so that the shell is stretched tight, then measure and record the maximum and minimum diameters (across axis at 90° to each other) using callipers accurate to 1.0 mm or greater.
- Add the two values together and compute the average for each egg.
- Measure and record the weight of the egg on a spring or electronic balance accurate to 0.5 g or greater.
- Repeat this procedure for all ten eggs.
- Record data on a form such as that provided in Appendix 7.12.3.
- Compute the mean and the standard deviation for the diameter and weight in each nest.
- Use the nest averages to compute location or year-class averages.

7.6.10 Measuring incubation temperature

Temperature of the sand affects embryonic survival, hatchling sex and the duration of incubation. The temperature usually varies within the incubation period and between seasons.

- Where equipment is available, incubation temperature should be recorded throughout the entire incubation period.
- Calibrate the thermometers prior to use at 15°, 20°, 25°, 30°, 35° and 40°C to establish any error in the devices.
- Place the thermometers at a depth of 50 cm in the general area where nests are deposited.
- If nesting density is high, a sturdy wooden stake should be driven into the sand to a depth exceeding 1m and the thermometer or probe placed adjacent to the post, to prevent disturbance by other nesting females.
- Record temperatures daily at 0600, 1200, 1800 and 2400 hours.

7.6.11 Hatching and incubation success

The easiest method to determine nest incubation success is to compare the total number of hatchlings that emerge from the nest with the original number of eggs deposited. Unfortunately, nests are often encountered hatching for which no original data are available. It is rarely possible to collect all hatchlings that emerge from a nest (unless they are penned in), as they crawl rapidly to the sea, and there may be multiple emergences from one nest over several days. It may therefore prove necessary to excavate the nests.

7.6.12 Measuring and weighing hatchlings

Hatchlings should be handled with caution and only when necessary. Natural dispersal of hatchlings from a nest site to offshore pelagic habitats involves a progression of behavioural responses, which are sensitive to disruption. Hatchlings should not be detained following their emergence without a specific purpose.

- Measure ten hatchlings from at least 10% of all nests, as soon as possible after emergence. Do not measure deformed or 'bent' hatchlings.
- Measure straight carapace length (SCL) from the nuchal scute to the notch between the post-central scales (as in measurements for adults, but using small hand-held callipers accurate to 1.0 mm or greater).
- Measure straight carapace width (SCW) at the widest point of the carapace.
- Weigh each hatchling (out of the wind) using a spring or electronic balance accurate to 0.5 g or greater (care must be taken to remove any adhered sand before weighing). This job may be simplified by placing the hatchling in a container on a pre-tared[1] balance, to prevent the hatchling from crawling away.
- Record all measurements and weights for each hatchling on a data sheet such as that provided in Appendix 7.12.4.
- Compute average and standard deviations for each measurement for individual nests.
- Use nest averages to compute a location or year-class average.

[1] Pre-tared: balance set to zero after container installed, or mass of container subtracted from gross weight of hatchling + container.

7.6.13 Determining hatching and emergence success

After incubation and hatchling emergence, nests should be excavated to determine the following:

(E)	number of hatchlings actually leaving the nest
(S)	number of empty shells - only count those that are more than 50% complete, do not count small fragments
(L)	live hatchlings left in the nest
(D)	dead hatchlings in the nest
(UD)	the unhatched eggs with no obvious embryo
(UH)	the unhatched eggs with obvious embryo (excluding UHT below)
(UHT)	the apparently full term unhatched or pipped eggs
(P)	any eggs that have been predated on (open, nearly complete shells with egg residue inside).

Where the original number of eggs was known, this should be compared to the value (S) to identify errors in nest excavation counts. Where the original number of eggs was not known but all hatchlings were counted, the clutch size (C) can be computed using:

$$C = E + L + D + UD + UH + UHT + P$$

An estimate (N) of total clutch size (C) can be computed if some of the hatchlings were not found using:

$$N = (S - (L + D))$$

To assess incubation success, one must establish hatching success (the number of hatchlings that emerge from the shells) and emergence success (the number of hatchlings that reach the beach surface). Hatching and emergence success can be computed using:

$$\text{Hatchling success (\%)} = (S / (S + UD + UH + UHT + P)) \times 100$$

$$\text{Emergence success (\%)} = (S - (L + D) / (S + UD + UH + UHT + P)) \times 100$$

7.6.14 Determining reproductive output

The reproductive output of a population may be used to make inferences on the quality of the nutrition available to turtles. As turtles nest many times in a season, the longer the duration of the survey the more accurate the data that can be gathered on the occurrence of re-nesting. Determining clutch size and hatching success provides invaluable information related to the reproductive output of nesting turtles, which is fundamental to their conservation and management. When reproductive biology data are analysed over the long-term, they can provide the foundation upon which management decisions are made. For instance, if the number of eggs deposited and which incubate successfully remains fairly constant, but the number of emerging hatchlings drops dramatically, this indicates some sort of problem with the nesting beach conditions (for example, cement dust at the Ras Baridi site in Saudi Arabia). Similarly, reductions in the number of hatchlings that reach the sea could indicate an increase in natural predators, which would need culling or controlling. Total reproductive output (O) can be computed using:

$$O = T \times R \times C \times I$$

where: T = estimated number of turtles

R = average re-nesting occurrence

C = average clutch size

I = average incubation success

Trends in reproductive output can be used to make assumptions indirectly on the state of the environment. Coupled with data on nesting turtles, long-term collection of data can suggest trends in population size, recruitment and mortality.

7.6.15 Re-nesting occurrence and interval

Calculating the re-nesting interval (how many days between successive nests) can provide an indication of the impact of research activities on turtles and on general population condition. Typically turtles nest on a two-week cycle though in some parts of the world they nest on a four to five week cycle. The re-nesting interval is calculated from the time of the last successful complete nest to the first subsequent nesting attempt, regardless of whether it is successful. This is because the simple act of emerging on the beach is already an indication of the intent to nest. The interval is calculated in days and averaged for the population.

7.7 GENETIC STUDIES

Genetic studies have helped answer important questions with regard to turtle conservation. They have proven that female turtles return to their natal beaches to nest and that there are discrete nesting populations (known as Ecologically Significant Units), which can be identified on nesting beaches and in foraging grounds. To identify discrete breeding populations, one needs to identify the characteristics of the mitochondrial DNA (mtDNA) molecule, which is a female-inherited marker, and nuclear DNA (nDNA), from which male-inherited information may be determined. These two studies should be conducted in a reputable laboratory by qualified technicians. Genetic identification of foraging populations is a priority activity. Samples can be taken from dried tissue on carcasses, small cuttings of rear flippers and dead hatchlings or embryos. These can be stored dry and dispatched for analysis to major sea turtle research centres such as the University of Queensland in Australia. All sea turtles are listed under CITES and an export and import permit will be required for shipping samples for genetic analysis. Note:

- Each turtle must only be sampled once (on foraging grounds either mark with paint or tag the turtles; for nesting turtles either mark the turtle or collect all samples within ten days to avoid re-nesting occurrences by the same female).
- Identify collection site and record GPS position.
- Use a large pair of nail clippers or a sharp scalpel to remove approximately 0.5 cm^2 of tissue from one of the rear flippers.
- Store in a securely closing sampling tube containing 70–90% ethanol or isopropyl alcohol (pharmaceutical grade).
- Clearly label the tube with a unique number that identifies the donor turtle. Samples may then be correlated with location, gender, species, size class, etc., at a later date.

- Use new scalpel blades or clippers for each individual to avoid cross-contamination of DNA material.

7.8 FORAGING AREA SURVEYS

Foraging area surveys are used to study turtles in their feeding areas underwater. They are usually carried out by trapping turtles in tangle nets, in relatively protected, open, shallow water areas, with little or no water movement (currents). Turtles are tagged and measured as in nesting surveys. Additional data is often collected on the state of ovarian maturity, diet composition and primary productivity of the foraging areas themselves. Foraging area surveys can be carried out at any time of the year, given that not all turtles leave a site to migrate to nesting sites. The survey periods should be timed to coincide with the best weather conditions. As turtles must be found from a boat, it is important to search when the sunlight penetrates at the steepest angle (midday) rather than when it reflects off the sea surface (mornings and evenings). As so little is known about the populations at foraging grounds in the RSGA region, it is suggested that surveys should be carried out whenever the foraging habitats are positively identified. The discussions below are restricted to seagrass beds, but capture and measurement methods are equally applicable to turtles caught on coral reefs.

7.8.1 Net captures

Netting is one of the most common methods of capturing turtles in foraging grounds. Nets can be set in ports or embayments where there are shallow water areas in which turtles rest. If turtles are known to be present in tidal creeks, nets can be set across the creek mouths at high tide and the turtles are captured as the tide falls. Nets are typically beach seine nets of large mesh size, set in the fringing lagoon and slowly pulled in to shore. This method is only practical when there are no coral and rock outcrops to snag the net when it is being retrieved. Given sea turtles' ability and agility underwater, nets should be relatively long (200 m or more), thus requiring several people for setting and retrieval.

Foraging waters are often slightly deeper than shallow, fringing lagoon waters and thus different types of nets are needed. Small purse seines and gillnets are sometimes used. Care must be taken to check the nets frequently so that entangled turtles do not drown. It is preferable to use fine mesh nets that do not entangle turtles as easily.

7.8.2 Typical tangle net characteristics

- Nets with a 40 cm stretch from knot to knot (20 cm on each side) are to be used for adult greens or loggerheads
- Nets with a 30 cm stretch (15 cm on each side) are to be used for juveniles, hawksbills and olive ridleys.
- Nets should be up to 4 m wide (deep) and should not be stretched completely when deployed.
- The top of the net should have pivoting marker floats (10 cm floats attached loosely so that they will 'stand up' when pulled from below, indicating the presence of something caught in the net).
- The bottom of net should be lead-weighted.
- Each end of the net must have an 8 kg Danforth-type anchor on about 15 m of line anchored to the top of the net.
- Nets should be a maximum of 200 m long.

7.8.3 Deployment (from a small boat)

- Set one anchor upwind (making sure it holds) and slowly reverse the boat, paying out the net.
- Record the time the first part of the net enters the water.
- Set the second anchor when all the net is deployed.
- Soak times for the net should not exceed two to three hours.
- Tend the net continuously and keep it in view at all times (while larger turtles might have the strength to swim up and breathe, many of the smaller turtles will not and might drown).
- Check the net manually by pulling the net upward hand over hand from the top line.
- If turtles congregate in an easily defined area, the net can be drawn around the turtles and made into a closed loop. Snorkellers can then enter the water to capture turtles by hand.
- Record details of each turtle, then mark and release. Record the time at which the last part of the net is removed from the water, to calculate the number of turtles caught per unit soak time.

If the net is set close to coral reefs (to trap hawksbills and juvenile green turtles) then:

- Snorkellers should swim the length of the net continuously, checking for net entanglement on the reef and for turtles (this should only be carried out when the visibility allows one to see the entire depth of the net).
- Scuba gear should not be used as the equipment can get entangled in the net.

7.8.4 Hand captures

If turtles are resting on the bottom or moving slowly, they may be captured by hand using scuba equipment or snorkelling. This takes much patience on the part of the researcher and safe diving practices must be observed at all times.

In shallow waters it is also possible to capture turtles from a small boat. Turtles are chased until they tire and slow down, at which point a diver jumps or dives into the water slightly ahead of the turtle to catch it. This method, known as Rodeo Capture, is only successful after much practice. It carries inherent risks through jumping from a moving boat including collisions, propeller cuts and hitting the seabed or the turtle with great force. It should only be attempted when the boat driver is extremely competent and the diver is a very good swimmer.

- Use a minimum of three people in a small boat with an outboard engine. The driver should be experienced, safety-conscious and remain at the controls the entire time; the second person should be the designated 'diver' and the third person should be an assistant).
- Follow the turtle until such a point as it tires and slows down.
- Jump in and attempt to grab hold of the turtle.
- Hold the turtle at the nuchal scales behind the neck and under the posterior end of the carapace, then tilt upward (the turtle will attempt to swim away, headed upward until he breaks the water at which point he can go no further).

- The boatman should then return quickly to the diver and turtle. Staff on-board must secure the turtle and bring it on board or to the beach.
- Once on board, the turtle can be tagged, weighed, measured and released.
- Record the exact location of the capture site with a GPS receiver.
- Record water depth and substrate type at point of capture.

7.8.5 Mark – recapture studies

These studies are used to estimate turtle abundance in foraging areas. Marking means any form of identification (can be standard tags, paint, scute markings), while recapture means any method of identifying the turtle at a later time. The assumptions underlying this method include:

- There are no deaths, births, immigration or emigration,
- All turtles have the same probability of being tagged,
- Tagging does not affect probability of recapture,
- Tags are not lost and are always detected,
- Recaptured turtles are a random sample of the population.

Population size (N) is determined by assuming that the proportion of tagged individuals in a sample is the same as the proportion of marked individuals in the population, and is computed using:

$$N = (nM / m)$$

where: n = number of turtles tagged in the first period,

M = number of turtles captured in the second period,

m = number of tagged turtles captured in the second period.

7.9 REMOTE MONITORING

Remote monitoring procedures are second generation studies used when the researcher needs to understand more detailed information on the turtle population for management purposes. They involve the attachment of data recorders/transmitters to turtles and subsequent data analysis. For details see ECKERT (1999).

It is important that whichever of these tracking methods is used, it must not interfere with the natural behaviour or the well-being of the turtle. Devices must be hydrodynamic in design and relatively lightweight (< 10% of the turtle's body weight). If using a harness, there should be some form of emergency release incorporated into the design.

7.9.1 VHF

This involves the use of a radio transmitter that beams a signal back to one or more shore-based receivers. This is a simple and easy-to-use method, dependent on acquiring a reading when an animal surfaces to breathe. It is not as accurate as other studies (rarely to more than 5–10% to each signal, resulting in a location accuracy of less than 10–20%).

7.9.2 Sonic telemetry

This is similar to VHF but transmits an underwater signal back to an underwater hydrophone. It is more accurate than VHF and other data can also be encoded in the signal (depth, temperature, etc). Sonic telemetry is more expensive than VHF and is not always useful in cluttered topographies (signal does not transmit through solid objects). Studies must be conducted from a boat, increasing costs and logistical concerns.

7.9.3 Satellite telemetry

Satellite telemetry involves attaching a transponder that transmits signals to orbiting satellites. Positional data along with additional information (e.g. depth, water temperature, dive data) is then emailed to the researcher. It is expensive (USD 7,500–10,000 per turtle) but, considering the costs of acquiring similar amounts of data by conventional tracking, it can prove to be more cost effective. It is becoming a well tested and widely used tool for studying turtle migrations.

7.9.4 Time-depth recorders

Time-depth recorders are relatively inexpensive electronic data loggers that can record depth data at set intervals. Upon recovery of the unit, the data can be downloaded to get an impression of diving behaviour, bottom time, dive depths and duration etc. It relies on the successful recovery of the unit.

7.10 FISHERIES INTERACTION STUDIES

Fisheries of various kinds have been implicated in significantly increasing marine turtle mortality rates. Shrimp and fish trawl nets capture turtles that often drown before the nets are retrieved. Turtles become entangled in fishing lines and ingest hooks of long line fisheries. Turtles are also entangled in gillnets and driftnets or caught in fish traps. By interacting with the fishing industry it is possible to gain knowledge of turtles that occupy habitats typically not monitored by turtle researchers. While there are no rigorous scientific methods for this process, below are a few examples of ways in which data can be collected through interactions with fishery operations.

7.10.1 Observer programmes

Researchers can seek permission to be present on commercial fishery boats, such as trawlers or long-liners, or to be present when pound nets are checked.

- Record geographical location (this can aid in distribution maps).
- Record species.
- Record sex (if mature, males can be differentiated from females).
- Note physical condition (alive and strong, alive but weak, comatose, dead).
- Determine morphometric measurements (body size and weight measurements: these can aid in determining size-class and age-group geographical distribution).
- Record the fate of the turtle (was it released, killed, thrown overboard?).
- Record any other noteworthy information.
- Tag turtles if they are to be released (even if they are not completely healthy, tagging and subsequent recovery can give a measure of survival rates for captured turtles).

7.10.2 Interviews

Following the format presented earlier (section 7.3), interviews with fishermen can yield valuable information on turtle distribution, often species and age-class specific. Through these, the researcher can identify areas in which turtles are found.

7.10.3 Analysis of catch records

By-catch are often recorded in a vessel's fishing log book which, coupled with information on the location of fishing operations at the time, can provide useful information on the geographical distribution of turtles.

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Appendix 7.12.1 Turtle identification sheet.
Marine Turtles found in the Red Sea and the Gulf of Aden.

Pictures courtesy of: Queensland Department of Environment and Heritage

Chelonia mydas **(Green turtle)**

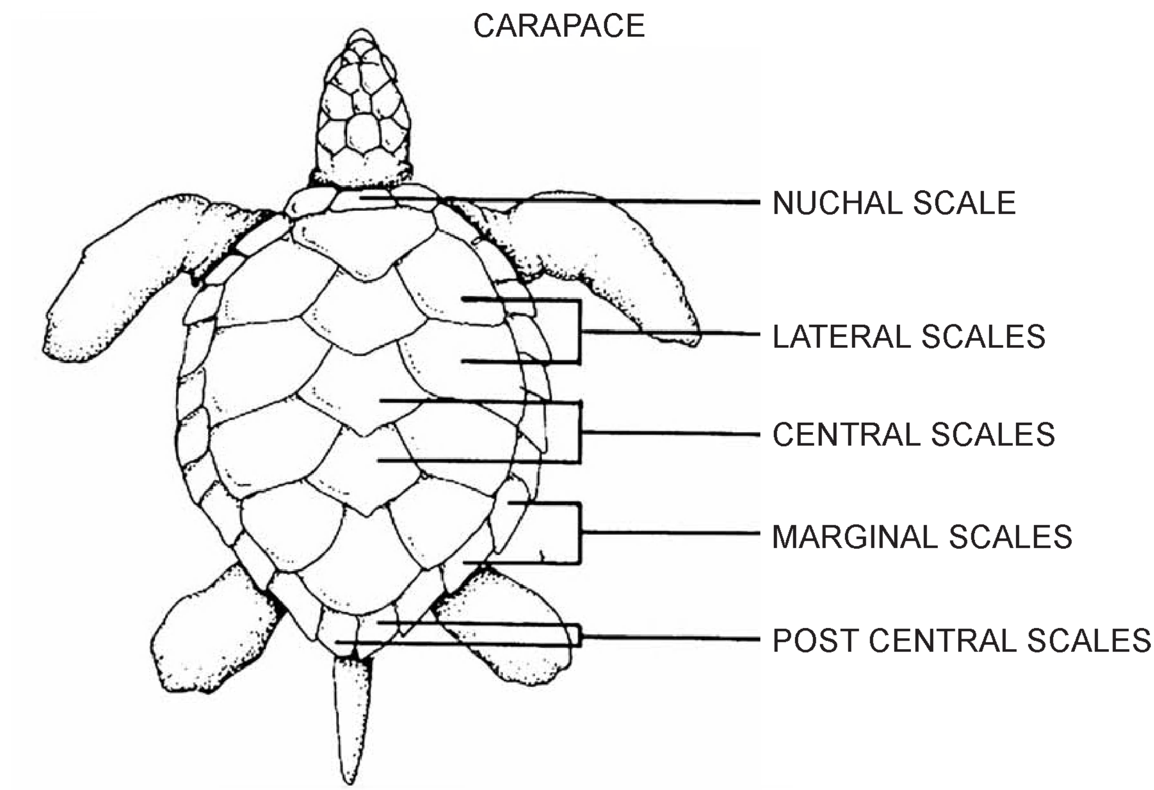
Eretmochelys imbricata **(Hawksbill turtle)**

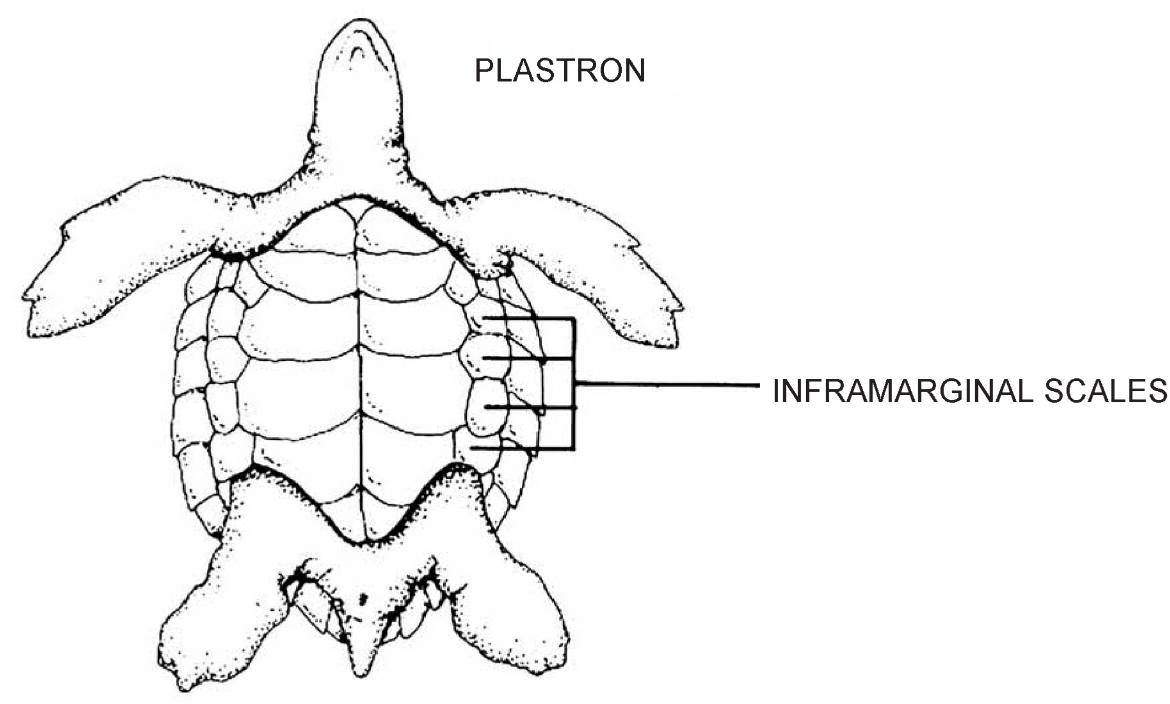
Lepidochelys olivacea **(Olive ridley turtle)**

Caretta caretta **(Loggerhead turtle)**

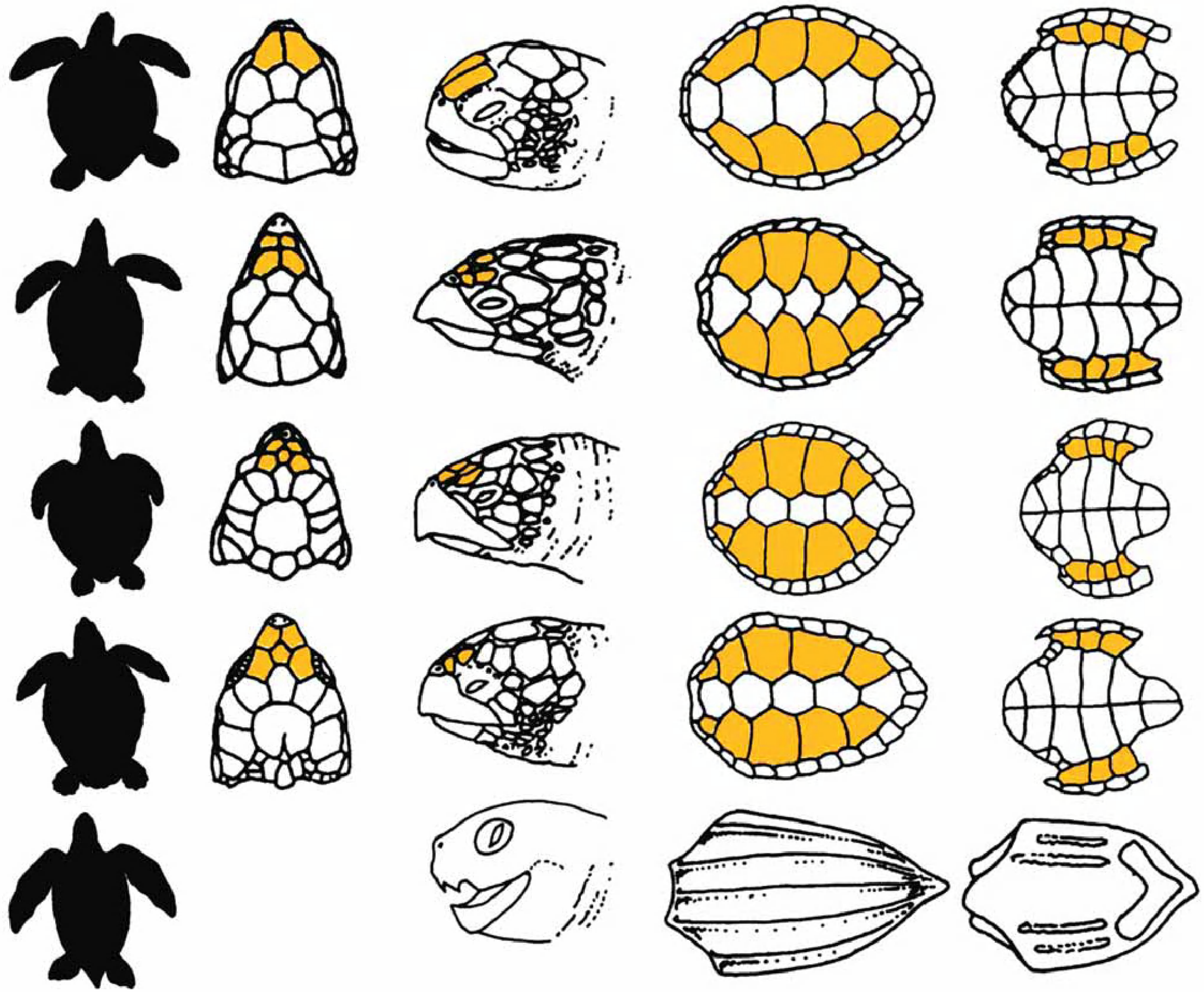
Dermochelys coriacea **(Leatherback turtle)**

Description of key identifying characteristics (source: MILLER 1989).





Description	Silhouette	Head (top)	Head (side)	Carapace	Plastron
Chelonia mydas **(Green turtle)** Head with one pair prefrontal scutes. Carapace with four lateral scutes, domed, light to dark green and mottled. Plastron with four inframarginal scutes without pores.					
Eretmochelys imbricata **(Hawksbill turtle)** Head with two pairs prefrontal scutes. Carapace with four lateral scutes, scutes imbricated (overlapping). Plastron with four inframarginal scutes without pores.					
Lepidochelys olivacea **(Olive ridley turtle)** Head with more than one pair of prefrontal scutes. Carapace with five, six or more lateral scutes, nearly circular, colour grey green. Plastron with four inframarginal scutes with pores.					
Caretta caretta **(Loggerhead turtle)** Head with more than one pair of prefrontal scutes. Carapace with five lateral scutes, longer than wide, colour red–brown. Plastron with three inframarginal scutes without pores.					
Dermochelys coriacea **(Leatherback turtle)** Head with no scales. Carapace with five distinct ridges and no scales.					



Comparison of external features. Diagrams not to scale. Modified from MILLER 1989 and ECKERT et al. 1999.

Location:		Site:	Activity: Emerging, Wandering, Digging, Chambering, Laying, Filling, Returning
Date:		Collector:	
Data Sheet No:	GPS Lat:	GPS Long:	Species: Green (Cm) Hawksbill (Ei) Loggerhead (Cc) Olive Ridley (Lo) All measurements in m or cm. All weights in Kg

Tag #	Time (24h)	Species	New (Y/N)	Beach Sector	Activity	Successful (Y/N)	# Pits	# Eggs	# Deformed	CCL	CCW	SCL	SCW	PL	PW	HW	TL	Track Width	Track length	WGT	Notes
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Appendix 7.12.2 Sample data collection sheet for nesting beach surveys.

Appendix 7.12.3 Sample data sheet for egg data collection.

Location:		Site:	
Date:		Collector:	
Nest Location:		GPS Lat: GPS Long:	
Nest #:		Species:	
Data Sheet No:		Tag #:	
Weight (g)	Diameter 1 (mm)	Diameter 2 (mm)	Mean Diameter (mm)
			Standard Deviation
			Mean Weight (g)
			Standard Deviation

Appendix 7.12.4: Sample data sheet for hatchling data collection.

Location:			Site:		
Date:			Collector:		
Nest Location:			GPS Lat: GPS Long:		
Nest #:			Species:		
Data Sheet No:			# Hatchlings Emerged:		
Weight (g)	SCL (mm)	SCW (mm)	Mean Weight (g)	Mean SCL (mm)	Mean SCW (mm)
			Stand. Deviation	Stand. Deviation	Stand. Deviation

8

SEABIRDS

8.1 INTRODUCTION

The seabird populations of the Red Sea and Gulf of Aden have been reviewed by COOPER et al. (1984), GALLAGHER et al. (1984), EVANS (1987) and JENNINGS (1995). These works have pulled together information from a wide variety of sources covering a fairly long time span. In the first two papers, the authors have attempted to estimate approximate population sizes, or orders of magnitude for some breeding species, thereby indicating the potential importance of the Red Sea and Gulf of Aden (RSGA) region in an international context.

However, closer scrutiny of the above reviews shows that little systematic survey work has been done on breeding seabirds in the region. There are a few exceptions where whole archipelagos have been covered, or national waters surveyed in their entirety (Table 8.1). Some works on avifauna have given estimates of national population sizes and breeding seasons for some of the more frequently encountered species. However, even where systematic surveys have been undertaken, there has been little use of a systematic methodology. The importance of the RSGA region for seabirds is not in doubt. Several endemic taxa occur, including the white-eyed gull *Larus leucophthalmus*, red-billed tropicbird *Phaeton aethereus indicus*, spoonbill *Platalea leucorodia archeri* and the brown noddy *Anous stolidus* *plumbeigularus*. A further group of taxa, at both specific and sub-specific level, is endemic to the NW Indian Ocean area. Important sub-populations of many of these taxa breed in the RSGA region. Species include the Jouanin's petrel *Bulweria fallax*, Socotra cormorant *Phalacrocorax nigrogularis*, sooty gull *Larus hemprichii*, swift tern *Sterna bergii velox* and white-cheeked tern *Sterna repressa*.

A brief review of the development of seabird survey methods in Europe puts this work in context. The NE Atlantic is an important area for breeding seabirds and there is a long history (30 years) of seabird monitoring. The baseline survey, Operation Seafarer, was undertaken in 1969–70. Professional ornithologists employed by conservation agencies, and amateur volunteers organised by the Seabird Group covered virtually all known coastal seabird colonies, using standardised but flexible methodology. Subsequently, a book was published (CRAMP et al. 1975), which summarised much of the numerical and distributional data in annotated maps. Relative colony size and species accounts were shown using administrative counties as the geographical unit for totals of pairs or individuals. A hard copy file of raw counts for each colony, island or coastal section was deposited in national libraries and amongst all organisations that assisted with the coordination of the Operation Seafarer survey. Fifteen years later, a slightly more rigorous methodology was proposed for a re-survey, the Seabird Colony Register (SCR), which was undertaken between 1985–87. Again a

Country	**National avifauna: atlas (A); list (B)**	**Important recent seabird studies: whole country (A); archipelago (B); single species in large area (C)**	**Name of archipelago**
Egypt	GOODMAN & MEININGER 1989 (A)	JENNINGS et al. 1985 (B)	Islands off Hurghada and much of Gulf of Suez
		HOATH et al. 1997 (B)	Mouth of Gulf of Suez
		FRAZIER et al. 1984 (A)	
Jordan	ANDREWS 1995 (B)		
	SHIRIHAI et al. 1999 (B)		
Saudi Arabia	JENNINGS 1995 (A)	ORMOND et al. 1984 (A)	
		NEWTON & SUHAIBANY 1996 (A)	
		GOLDSPINK et al. 1995 (B)	Farasan
		JENNINGS 1988 (B)	Farasan
		SYMENS 1988a (B)	Farasan
		NEWTON & SYMENS 1996 (C)	
Sudan	NIKOLAUS 1987 (A)	MOORE & BALZAROTTI 1983 (B)	Suakin & Mohd. Qol
Eritrea	SMITH 1951 (B)	CLAPHAM 1964 (B)	Dahlac
Yemen	JENNINGS 1995 (A)	EVANS 1989 (B)	Al Luhayyah
	BROOKS et al. 1987 (B)	PORTER & AL-SAGHIER 1998 (B)	Al Hudaydah
	PORTER et al. 1996 (B)		
Djibouti	WELCH & WELCH 1984 (B)		
Somalia	ASH & MISKELL 1998 (A)	NORTH 1946 (B)	Mait Island
Socotra	KIRWAN et al. 1996 (B)		

Table 8.1 Sources of information regarding seabird numbers and distribution in the RSGA region.

book was published, LLOYD et al. (1991). This provided a critique of discrepancies between the two surveys, in the light of the different methodologies used for different groups of species. The major difference between the two surveys was that the principal output of the SCR was a computer database. This has been updated annually for a sample of colonies that are monitored regularly as part of the Seabird Monitoring Programme (SMP).

WALSH et al. (1995) have produced a very comprehensive manual of suitable methodologies, that covers basic census and more intensive productivity monitoring. There is now much greater use of standardised methodologies and these are presently being used in a third census of all colonies in Britain and Ireland called Seabird 2000.

Surveys in the RSGA region and elsewhere in the Middle East prior to the 1990's were typically done during brief, opportunistic 'walk-around' visits. However, the Gulf War of 1991 and the ensuing serious oil pollution in the northern Arabian Gulf (EVANS et al. 1993) changed the course of seabird studies in the region. An environmental disaster can act as a stimulant for improved monitoring and protection of the marine environment. Detailed research carried out on the Saudi Arabian Gulf islands between 1991 and 1995 has resulted in refined methodologies for the census of summer nesting terns (SYMENS & EVANS 1993; SYMENS & AL SUHAIBANY 1996) and winter breeding Socotra cormorants (SYMENS et al. 1993; SYMENS & WERNER 1996). All tern species monitored in the Gulf are also breeding in the RSGA region and the methods are directly applicable. The Socotra area itself is fairly peripheral in the breeding range of Socotra cormorants, though small numbers may nest near the coast of Yemen and survey methods given in SYMENS & WERNER (1996) would be appropriate.

During the early 1990's, several RSGA countries and others in Arabia began to contribute counts of wintering waterfowl to the International Waterfowl Census, organised by the International Wetlands Research Bureau (now Wetlands International). Within Saudi Arabia, only relatively small sections of the Red Sea coastline could be covered by ground counts. However, the availability of light aircraft used for protected area patrols with the National Commission for Wildlife Conservation and Development (NCWCD) enabled much larger areas to be covered from the air. This aerial survey work was usually undertaken in January/February outside the main breeding season for seabirds. However, it soon became apparent that some species were nesting in the winter on some inshore islands, e.g. pink-backed pelican *Pelecanus rufescens*, brown booby *Sula leucogaster* and Caspian tern *Sterna caspia*. With practice, methods and routes were refined so that these species and their nests could be counted. Subsequently, the numbers and distribution of pelicans especially, became better known (NEWTON & SYMENS 1996). The next logical step was to expand aerial coverage to summer breeding seabirds and in 1993 a full aerial survey of the Farasan archipelago was undertaken (GOLDSPINK et al. 1995). ground-truthing was also done to assess the accuracy of the aerial counts. Following extensive planning, a survey of all other Saudi Arabian Red Sea islands was completed in summer 1996, together with a re-survey of some of the Farasan Islands (NEWTON & AL SUHAIBANY 1996a, 1996b). Thus, work completed in the Arabian Gulf and Saudi Red Sea has resulted in a variety of suitable methods being developed. Their application to the wider RSGA region is pertinent. However, for some species we are still woefully short of information on the precise timing of nesting seasons and whether these vary from year to year. For petrels (Procellariidae), which only visit their colonies during the hours of darkness, we also lack an understanding of nesting habitat.

8.1.1 Definitions

True seabirds:

Typically defined for the RSGA region as members of the following families, which are dependent on the marine environment for the whole of the annual cycle: petrels and shearwaters, tropicbirds, boobies, cormorants, gulls and terns.

Other seabirds:

Those families associated with the marine environment for the breeding season and typically for much of the annual cycle: pelicans, some herons and egrets, spoonbills.

Raptors and waders:

Osprey *Pandion haliaetus* and crab plover *Dromas ardeola* are representatives for each group that are dependent on the marine environment in the RSGA. Although sooty falcons *Falco concolor* nesting in the RSGA region utilise marine islands, their food base typically consists of migrant passerine and near-passerine birds. Additionally, many Kentish plover *Charadrius alexandrinus* nest on mainland beaches and islands and utilise intertidal areas for feeding on invertebrates; some also nest inland around freshwater, the margins of rivers, lakes and reservoirs.

8.1.2 Breeding Seasons

Three seasons are referred to in the following text; the commencement of a season is marked by egg laying. Summer breeders refer to those species that appear to lay principally in late May to July (most terns). Winter breeders, including Socotra cormorant, pink-backed pelican and osprey, may initiate clutches from the autumn (October) onwards, but the former species may nest in "waves", over a protracted period. Spring breeders are those that lay between February and late April, and include Caspian tern, Saunder's tern *Sterna saundersi*, herons and spoonbills. Some species such as the brown booby have been found at nests in most months of the year. This situation could arise for several reasons. Timing may vary in response to prey abundance in different areas at different times. Nesting could occur at sub-annual intervals. Finally, there may be several nesting "waves" at particular colonies, with more experienced breeders commencing earliest and less experienced pairs later. Only regular visits to key sites over a period of several years will throw light on this situation.

These guidelines propose a framework for the collection of information on breeding seabirds from countries bordering the Red Sea and Gulf of Aden.

The specific aims for each country should include:

- Production of a national inventory of seabird colonies in which the following topics are covered:
    - species present, breeding status, number of pairs (or individuals), habitats utilised;
    - size, topography and habitats of each island/colony;
    - timing of nesting or occupation of islands/colonies;
    - human activities on or around each island/colony, direct and indirect threats to seabirds;
    - conservation actions needed, especially where human occupation has been noted or sensitive species are present.

- An estimate of geographical (regional) population sizes and an evaluation of the relative importance of sites. Those holding 5% or more of the biogeographical population may be considered of international importance. Such criteria for seabirds differ from RAMSAR Convention regulations, where sites holding 1% of a biogeographical population or 20,000 waterfowl are considered internationally important.
- Production of a Conservation Action Plan which integrates seabird data with other national/regional coastal initiatives towards the establishment of marine protected areas (MPAs) and the implementation of integrated coastal zone management (ICZM) strategies.

8.2 METHODS

8.2.1 Phase 1: Desktop Planning

The senior ornithologist in each country should commence by preparing a list of all islands in their territorial waters (Gulf of Suez, Gulf of Aqaba, Red Sea, Gulf of Aden). All available maps, and perhaps satellite images, both hard copy and electronic, should be scrutinised. In the RSGA region, virtually all seabird colonies are on islands, as they are free from the majority of terrestrial predators. However, remote sections of mainland coast with sand spits are also relatively inaccessible. Cliffs should be added to a reserve list to check as a second priority. Also, mainland bays that harbour dense mangroves often contain isolated stands that form small islands without a solid substrate. These can be utilised by tree-nesting species such as pelicans, herons and spoonbills. Again, add such sites to the secondary site list.

Maps

The following maps are usually sufficiently accurate and identify most permanent islands:

- British Admiralty Navigation Charts or other local equivalents
- UK Ministry of Defence including:

  Operational Navigation Charts (ONC) Series 1:1,000,000, for example,

  - ONC H–5 North Red Sea, Suez, Aqaba
  - ONC J–6 Central Red Sea
  - ONC K–5 Southern Red Sea
  - ONC K–6 Gulf of Aden

  and:

  The Tactical Pilotage Charts (TPC) Series at 1:500,000. Source: Air Force, Airlines, smaller aircraft charter companies.

The latter offer much more detail and are perhaps the best for making initial lists of islands. There are four sheets for each ONC, with alphabetic coding as follows: A = northwest; B = northeast; C = southeast; D = southwest. For example, sheet TPC J–6C covers the southeast part of ONC J–6 i.e. a small part of the Red Sea coastline on the Saudi/Yemeni border.

The Ministry of Petroleum & Mineral Resources, Kingdom of Saudi Arabia (KSA), produces some good maps at 1:500,000 scale. Other countries probably have equivalent maps produced by the national authority that regulates oil exploration.

The information extracted from maps should be entered into an EXCEL type spreadsheet under the following headings:

- Name (real or geographically based, e.g. island southeast of Jazirat One); note any alternatives in use.
- Latitude (central point if large island)
- Longitude (as above)
- Approximate island size (three categories: (A) small <500 m; (B) medium 501–5,000 m; (C) large >5,001 m, all measured along the long axis)
- Any other details (presence of fishing villages, coastguard stations, mountains plus spot height etc.)
- The overall coastal zone should be split into several sectors that may eventually form reasonable field survey units.

Literature

Once the planning team is familiar with the distribution and names of islands in territorial waters, the ornithological literature can be reviewed. Many general references to the RSGA region can be found in the 1990 ALESCO–PERSGA bibliography edited by MORCOS & VARLEY (pages 132–134 for birds) and its companion volume containing references for the period 1985–1998 (PERSGA/GEF 2002). More recent papers are listed at the end of this document. Literature should be classified under two headings: historical (pre–1980) and recent (1980–2003). Experience has shown that the situation described in recent papers is usually still applicable today, unless there have been significant military or tourist infrastructure developments at the location in question. Information extracted from the literature should focus on the breeding status of species present at the time of the survey. Most surveys were typically brief 'walk-around' visits, and population estimates are usually vague. However, one should be able to extract lists of which species were present, those proven to be nesting, nesting habitat and a broad evaluation of numbers on an order of magnitude scale:

A = 1–10 pairs,

B = 11–100 pairs,

C = 101–1,000 pairs,

D = 1,001–10,000 pairs and

E >10,000 pairs.

Again, such information can be entered on the EXCEL file as species; breeding (Yes / No); and order of magnitude (A–E).

Two lists of islands (derived from historical and recent texts) should then be ranked in order of importance for breeding seabirds.

8.2.2 Phase 2: Resource Review

Resources should be reviewed to assess availability under the following headings: personnel, transport, equipment, contacts and liaison with other organisations.

Personnel

List those personnel in your organisation who can either participate in surveys, or act in a support capacity in the field or in the data analysis/presentation phase. Note their ornithological skills on a three-point scale of 'some', 'reasonable', 'good' for the following: bird identification, bird census or counting experience, survey techniques (knowledge of transects/quadrats), bird ringing.

Also record other skills that will be useful in seabird surveys including boat handling, ability to swim, navigation e.g. use of compass and GPS, knowledge of particular geographical areas, local contacts.

It is unlikely that many national organisers have an abundance of experienced staff available. A training programme may need to be considered.

Transport

The availability of vehicles, boats and light aircraft needs to be assessed within your own organisation and within others that may be able to assist you in reaching particular islands. A useful exercise is to annotate coastal maps with the locations of coastguard stations, navy bases, fisheries patrol vessels/bases, fishing villages, marinas and pleasure boat moorings, marine research centres and so on. Try and find out which islands are covered by staff from these institutions and thereby identify gaps where you will have to use your own boat or charter some alternative.

Equipment

Relatively little scientific equipment is required for basic seabird surveys other than the usual binoculars, telescopes and tripods. Waterproof notebooks or diving slates are useful during very humid times of year. If detailed nest counts are to be undertaken in dense colonies, then a variety of light ropes (50 m in length) and tape measures will be needed. GPS (with water tight 'aquapac' pouches to keep them dry), compasses and other marine navigation and safety equipment will be needed for offshore work and travel. The use of computers and data analysis software is addressed at a later stage. Generally speaking, use of laptop computers in the field is not advisable owing to dust, sand, humidity, etc.

Contacts and Liaison

Within your own organisation, liase with other specialists (e.g. those working on turtles, marine mammals and mangroves) regarding their survey programmes. Sharing transport or survey flights is beneficial in reducing costs.

Outside your own organisation, initiate communication with a range of useful contacts (as above). In some instances you may be able to recruit volunteer birdwatchers from natural history societies who could assist in field surveys. Identify all sites deemed sensitive for military or national security reasons; these should not be visited by field survey teams.

8.2.3 Phase 3: Fieldwork Options

To produce a national seabird colony inventory two main tasks have to be accomplished:

- A systematic reconnaissance (which islands are used by seabirds, which species are present, whether they are nesting) and
- A more detailed monitoring of the more important, accessible, sites and colonies in which actual numbers may be assessed.

Aerial Survey

Both fixed-wing aircraft and helicopters can be used to carry out aerial surveys.

Fixed-wing aircraft

These are perhaps best for rapid reconnaissance. In summer 1996, virtually all islands in the Saudi Red Sea were overflown in a series of 12 missions (flights) that ranged in length from two to five hours flying time (NEWTON & AL SUHAIBANY 1996a). A basic procedure follows:

- Discuss your rough itinerary with the pilot several weeks in advance. The pilot will advise you as to restricted areas, range and flying time with different numbers of observers etc. Time will be needed to apply for and receive approval of flight plans.
- The day before your flight, give the pilot a numbered list of coordinates for all islands/sites you wish to fly over on the next day. The pilot will enter these into the aircraft GPS and this will relieve you of much navigational responsibility during the flight so that you can concentrate on identifying and counting birds.
- Immediately prior to your flight (one hour), take motion sickness pills if necessary. Check you have all necessary maps and recording forms plus sufficient drink and food (easy to eat in a confined space). Divide data collection topics between the number of observers you have (usually one to three). For example, one observer may record island information (size, substrate, signs of human occupation, habitats etc.) and the other(s) record bird counts. The most experienced person should do the latter.
- Once airborne over the sea in your target area, fly at 100–300 feet (30–90 m) above sea level as slowly as possible (probably about 90 knots). Usually, several overpasses of each island will be required to cover the range of species. If two bird counters are present, split the species, or one count nests and the other birds. In the first few surveys, try and evaluate which species flush first and disperse furthest on approach by the aircraft and those which stay together for longer in more detectable flocks. Several overpasses are often necessary to flush species that nest under thick cover, e.g. brown boobies. Non-breeding birds tend to flush and disperse first, whereas those on nests with eggs and/or chicks are usually most reluctant to fly off. Once bird counts have been made, if time and fuel permit, make a further overpass to photograph dense colonies. Over smaller islands (size classes A and B) you should not spend more than 5 minutes overhead, and often a lot less. Aerial surveys in summer should be confined to early morning (0600–1030) or late afternoon (1500–1830) to minimise heat stress on adult birds or their eggs and chicks. During winter, a longer part of the day may be used.

Helicopters

These tend to be noisier, slower and probably cause more disturbance to nesting birds than fixed-wing aircraft. However they may be better as platforms for aerial photography of dense colonies (e.g. Socotra cormorants, pink-backed pelicans), given their ability to remain stationary. The helicopter should not fly too low as the downdraft from the rotors can blow eggs and chicks out of their nests. See SYMENS & WERNER (1996) for more details.

Boat Survey

Boats will usually be used to gain access to islands. Larger and faster boats are better for access to more remote offshore or distant locations. An inflatable dingy with outboard engine may be needed to land on many islands with barrier reefs. During crossings of open sea, try and maintain watch for seabirds, particularly petrels and shearwaters. This may be the only opportunity to discover which nocturnal or burrow-nesting species are present in your area, as they will not be seen during daylight visits to islands. In some instances, it may not be feasible to land, and a boat circuit of the island may be your only opportunity to see which species are present.

Landing may be prevented if the sea state is too rough, if the island is totally surrounded by impenetrable reef or inaccessible cliffs or if you simply have insufficient time. For small (Class A) islands, a sea circuit may provide enough information. It may be necessary to count cliff-nesting species such as tropicbirds. If a prior aerial reconnaissance has not been done, a boat circuit can be useful to indicate presence and distribution of habitats and species to help plan a strategy once you are on the ground. Some nesting species, e.g. brown boobies, should not be approached closely during the incubation and early chick stages as they are unable to defend their nests from marauding white-eyed or sooty gulls, which are usually present around the periphery of colonies.

Landing on Islands

Both the time available and the size of island are pivotal in deciding how to conduct the survey. Often some spells of careful observation from higher vantage points may be a better use of time than a mad rush to walk to each corner of the island or around its perimeter.

Class A–size islands

Plan to spend about two hours on land for a rapid assessment, as long as your presence is not continually disturbing all nesting birds on the island. All areas can be reached on foot and even mangrove stands or dense shrubbery can be checked.

Class B–size islands

Allow eight hours, i.e. all day, and try and pick a day with some cloud cover, so that personal exhaustion and dehydration do not influence your results.

Class C–size islands

Islands of this size may have permanent human settlements of one sort or another in which case vehicles may be available to move about the island (e.g. Farasan Kebir and Segid in the southern Saudi Red Sea or Dahlac Kebir in Eritrea). However, it is also likely that cats, rats and mongooses will be present and large seabird colonies are improbable. For example, the only seabirds nesting on Farasan Kebir away from tall, dense stands of mangrove are a couple of small Saunder's tern colonies on more remote sandy beaches or headlands. It may require several days to cover such islands adequately.

The following sections describe methods appropriate to all species known to nest in the RSGA region. However, some basic methodologies are common to various species groups, or habitats, and will help in the rapid assessment of islands if time is limited.

8.2.4 Terrestrial Methods

Most methods require an estimation of nest densities in different habitats and then the extrapolation of densities to the approximate area of the island covered by that habitat type. Prior awareness of the types of situations in which various species nest and colony types will help in allocating search effort. Two slightly different approaches are needed to determine the potential number of nesting seabirds, depending on whether they are semi-colonial or colonial. For the former, e.g. bridled terns, vantage points need to be located and counts made after the birds have resettled. If counts are conducted during incubation, note that one member of a pair incubates while the second frequently perches above the nest on the top of a bush. Thus, the total number of perched birds approximates the number of pairs in the area. In more compact colonies, e.g. white-eyed gulls and white-cheeked terns, it is necessary for two observers to walk in parallel three to five metres apart and record the number of nests and clutch sizes. The following descriptions give examples of habitats in which dispersed, semi-colonial and colonial species are found.

Dispersed species

- Territorial, e.g. osprey, possibly goliath heron, *Ardea goliath*, and purple heron, *A. purpurea*, (but in dense mangrove).
- Scarce habitats, e.g. red-billed tropicbird in caves/niches, in cliffs or fossil coral overhangs.

Semi-colonial or loosely colonial species (may cover whole island)

- Ground nesters, e.g. Caspian tern, Saunder's tern, brown booby, sooty gull (usually beside or under some cover).
- Under light vegetation, e.g. bridled tern, also under overhangs in fossil coral.
- Sub-colony, in or under medium height vegetation, e.g. little green heron *Butorides striatus*, western reef heron *Egretta gularis*, and brown noddy.

Colonial species (usually discrete entities covering relatively small parts of island)

- Ground nesters, very compact colonies, large numbers, e.g. swift and lesser-crested terns *Sterna bengalensis*, Socotra cormorant.
- Ground nesters, compact colonies but inter-nest distances 1–5 m e.g. white-cheeked tern, white-eyed gull.
- Underground nesters, usually in dunes/berm or other sandy area, e.g. crab plover.
- Tree nesters, usually on canopy, e.g. pink-backed pelican, spoonbill, cattle egret *Bubulcus ibis*.

8.2.5 Ringing

Bird ringing is a widely used tool in ornithological monitoring studies. In general, ringing does not have a significant role in standard surveys aimed at assessing population size. The key information to be gained from ringing concerns the survival and mortality rate, longevity, breeding site fidelity, and distribution patterns for birds using the RSGA region in, or out of, the breeding season. As adults, seabirds are not easy to catch, given their normal habit of nesting in open habitats. Thus, most seabird ringing involves catching and marking pre-fledging chicks; large numbers can be ringed relatively quickly in nesting colonies. However, seabirds are usually long-lived and do not return to breeding areas for several years. Information is gained from the use of standard metal rings only when the individual is recovered, i.e. found dead or deliberately killed, or re-trapped. Use of field readable colour rings increases the likelihood of detecting ringed birds. A single colour can be used to indicate chicks ringed in a particular year or location (colony or island).

Chick ringing can be used in intensive, single site based studies to give information on survival and fledging rates. It can also be used in mark-recapture studies that indicate efficiency in finding chicks for species that tend to hide in vegetation.

Although ringing is not a census tool, it is always worth checking the legs of all dead birds found while doing fieldwork. Ring recovery can yield important information about the origins of birds in a colony.

8.2.6 Threats to Nesting Seabirds

The majority of seabirds nest in close proximity to each other in colonies. This increases their overall vulnerability to disturbance from human visitors or predators. When visiting seabird islands, one should always be aware of the disturbance being caused and try to minimise the impact of the visit. However, while on islands collect as much information as possible, not only on the birds themselves but also on human uses and their likely impact, and on predator presence or absence. If you are present in an archipelago for several days, talk to as many local inhabitants as possible, especially coastguards and fishermen, and assemble a short log-sheet of useful information to supplement your own observations.

Factors threatening the well-being of breeding seabirds are numerous and include oil pollution, overexploitation of fish stocks and habitat destruction (e.g. from development or overgrazing of mangroves, see EVANS 1987).

Human Disturbance

Casual human visits to breeding islands can cause significant disturbance to nesting birds even if there is no deliberate interference. In many areas, access to islands is under the control of the local coastguards. Landing may be forbidden, except on designated islands where overnight shelters and “temporary” camps are sometimes established. However, rules and regulations are seldom rigidly adhered to, and undesignated islands can often become popular breakfasting and meeting places amongst fishermen; disturbance is caused when they search for firewood etc.

Small agile species such as terns respond swiftly to intruders, though their mobbing response is much reduced and not as persistent compared to closely related species nesting in temperate or Arctic conditions. Terns also resettle relatively rapidly. Even so, the heat stress on eggs or small chicks exposed during the middle of the day is potentially very damaging. For some larger species, being forced to leave their nests can give sufficient time for predators to steal eggs or chicks. This has been observed for brown boobies: in flight over land, the adults are not very manoeuvrable and have difficulty in returning to their nests, thus allowing sooty, and possibly also white-eyed, gulls time to steal eggs. Once chicks are able to move independently, disturbance may cause them to break cover and walk or run out of their natal territory where they become vulnerable to harassment and sometimes predation by neighbouring conspecifics (observed in sooty gulls). Sometimes parents of such displaced chicks may fail to relocate them, or feed them, once they are away from their own nests.

Human Exploitation

This can take one of two forms: collection and consumption of eggs, or chicks. Currently the latter does not appear to be a problem in the Red Sea region, though it is, or has been, a traditional activity elsewhere especially at Socotra cormorant colonies in the Arabian Gulf and off southern Oman. Anecdotal evidence can be collected from local towns, which may indicate if food exploitation is taking place presently or has in the past. The collection of eggs of tropical seabirds, particularly terns, is a widespread phenomenon in the Indian Ocean, Red Sea and Arabian Gulf. Based on experience in the Farasan and Al Wajh archipelagos, Saudi Arabia, it is often difficult to ascertain how deliberate or planned egg collecting is, or whether it is mainly opportunistic. Egg collecting is not restricted to fishermen or local villagers, but can also be carried out by government officials. If egg collecting takes place early in the nesting cycle it may have relatively little impact as the birds have sufficient time to re-lay. However, repeated collecting may have a severe impact on the distribution and overall breeding success of terns, with long-term consequences at the population level. Egg collectors leave a trail of footprints. These can easily be distinguished from those of casual visitors, particularly when they move between and around vegetation patches systematically looking for bridled tern nests, or they link a chain of empty white-cheeked tern scrapes.

Introduced Predators

Cats are often deliberately brought to new human settlements on offshore islands, such as fishing camps and coastguard stations, to control rodent populations. However, some introductions are no doubt accidental from concealed ship borne animals. Cats soon become feral and numbers can increase rapidly, with waste human food and garbage acting as a buffer against seasonally fluctuating natural food supplies. The white-tailed mongoose (*Ichneumia albicauda*) is also present on some of the larger Red Sea islands. These small carnivores have been shown to affect the breeding success of large species such as ospreys (FISHER, pers. comm.) and they may be the principal factor preventing ground nesting seabirds from using certain islands.

8.2.7 Census Techniques

Count Units

Make sure that count units and methods are recorded on field sheets or notebooks. The following can be used as count units:

- Individuals: usually for non-breeding birds or aerial counts where sub-canopy nest cannot be seen.
- Occupied (adult present) or Active (egg or chick present) Nests: either from ground or aerial counts.
- Nests: vacated or contents not visible and present breeding status thus indeterminate.

Aerial Survey

Two approaches can be used in isolation or in combination: direct counts and aerial photography. If sufficient personnel are airborne or if the area to be covered is relatively small, using both is preferable. Photography is most appropriate if personnel are relatively inexperienced, although learning to make rapid but approximate estimates is a valuable skill to acquire. Films can be lost by developers or may lack quality (poor exposure or focus). Tally (clicker) counters are very useful. To speed up the process count in units of ten, or 50 if numbers are large. The present availability of motor drives, rapid autofocus and zoom lenses has made aerial photography very easy and reliable. Choice of film type (slide versus print) is not important though if the latter are used, then print size needs to be somewhat larger than standard (i.e. at least 30 x 20 cm). Using a camera that prints date and time onto each shot can save much writing whilst in the air. However you should always record notes of island, sub-section etc. on a film shot log that can be crosschecked with the recorded route/time log that the pilot or navigator will keep. Once back at base when the films have been developed, procedures for analysis of prints and slides are slightly different.

Prints

Several good quality copies are made (generally enlargements, sometimes photocopies) and assembled into an overlapping mosaic. An island colony is divided into sub-sections drawn on the prints and each team member marks nests (cross or circle) with a fine pen. The exercise is repeated several times and the average count used. Remember to include the count unit on your data sheet: individual birds e.g. roosting cormorants; occupied or active nests; or vacated nests.

Slides

Project slides onto large sheets of white paper, where they can be marked in the same way as prints. It is usually more difficult to separate adjacent sub-colonies reliably on slides, as they cannot be viewed simultaneously.

Several useful papers review topics such as the comparability of print versus slide media and detailed counts versus estimates (e.g. REYNOLDS & BOOTH 1987), and between-observer variability in colony counts, for photographs (HARRIS & LLOYD 1977). Aerial photographs provide good records of the actual location of colonies on particular islands and how they grow if the population is increasing (e.g. HILL 1989). Photographic records can also be very useful during subsequent ground visits.

Ground Counts

The main ground count techniques used do not require equipment other than binoculars or telescopes and include: counts from vantage points, flush counts, and walk-through counts. More time-consuming methods such as belt transects (for terns) and quadrats (for terns and cormorants) require some basic mapping and need ropes, tape measures, compass and bamboo canes (or similar) as markers.

Vantage Points

This method requires the presence of dunes or other slightly elevated terrain from which to observe the colony. Count the number of occupied nests using binoculars or telescope. If the colony is fairly large, split it into sections first, using landmarks that you can relocate with ease. Suitably chosen vantage points cause little disturbance but are best used for small to medium sized colonies. Where birds are very densely packed or the colony is very large, different sampling procedures will have to be used.

Flush Counts

These can be used when the nesting birds (usually those incubating or with small chicks) rise up with reasonable synchronicity, and fly around above the colony in a relatively compact flock on approach by a human. It is especially useful for terns in medium to large sized colonies. Always attempt counts, even if you intend to walk into the colony to undertake a nest count. The count unit is of individual birds and the mean of several counts should be recorded. The relationship between the number of birds counted and the number of pairs or nests present varies with the stage of incubation and species. Validation studies need to be conducted if it is necessary to convert individual counts to numbers of pairs or nests. For example, BULLOCK & GOMERSALL (1981) give a conversion factor of 1.5 for temperate nesting common and arctic terns during late incubation in Scotland. In this case, a count of 100 individuals would be eqivalent to 67 nests. SYMENS & ALSUHAIBANY (1996) give similar information for white-cheeked and bridled terns nesting in the Arabian Gulf, although the conversion factors may not be exactly replicable for the RSGA region.

Walk-though Counts

In small to medium sized tern or gull colonies, walk-through counts can be effective. Depending on nest density, two or more observers walk in parallel through a colony, counting nests on either side within half the distance between the next person. Tally counters are useful, especially if you are recording clutch sizes or several species in the same colony. If several passes through the colony are needed, then it can be useful to lay a rope through the colony to delimit the area you have covered. On sandy substrates your footprints can also be used to prevent double counting.

An alternative technique, which does not require *in situ* counting is as follows: enter the colony with a bag containing a sufficient quantity of counted, dry, pasta pieces. Place one piece in each nest as proof that it has been counted. Once the colony is finished, subtract the number of remaining pasta pieces from the initial total to get the number of nests. Do not use this method if large numbers of rodents (mice or rats) are present on the island.

Belt Transects

Belt transects are most suitable for species which do not nest at extremely high densities such as white-cheeked tern and bridled tern. Transects are conducted at regular intervals of 100–500 m parallel to the short axis across an island or colony. For each nest found, record species, clutch size and location along the transect. Also record total transect length. Use densities calculated from these data to estimate total populations for each island or colony (see SYMENS & EVANS 1993; SYMENS & ALSUHAIBANY 1996).

Quadrats

Both swift and lesser-crested terns nest at extremely high densities. Belt transects right through colonies would cause excessive disturbance. Instead make a lightweight frame of rigid wire measuring 1 x 1 m. Lay this carefully down at a selection of locations evenly spread across the colony and count nests. The number of 1 m^2 quadrats counted will depend on the time available and colony size. Between ten and 30 should be adequate. While one person or team counts the nests, another should draw a map and measure the size of the colony (at least the maximum length and breadth), so that the quadrat density estimates, when averaged, can be extrapolated to the area of the colony. This technique is particularly suitable during the incubation period.

Counts of Nest Structures outside the Breeding Season

This method can be used for large Socotra cormorant colonies, and perhaps swift and lesser-crested terns and brown boobies, when the colony has been vacated. Nest scrapes, mounds or depressions can be identified and counted, or sampled by transects or quadrats. Counts may indicate the maximum number of pairs that attempted to breed in the previous season. SYMENS & WERNER (1996) give details and limitations of this technique, but note that heavy rainfall may obliterate much evidence of nesting.

8.2.8 Methods for Species Breeding in the RSGA region

The following section includes specific details for individual species breeding in the RSGA region. Where known, the habitats utilised, colony type and nesting season are also given.

Jouanin's petrel *Bulweria fallax*

Area: Socotra and neighbouring islands.

Habitat and colony type: Caves in coastal cliffs of soft limestone.

Nesting season: Summer – autumn (eggs July, fledglings November).

Appropriate methods: None described; the nesting cliffs are treacherous and inspection would require competent rock climbers with ropes. Inspection of a sample of caves covering the range of sizes (depth, diameter of entrance etc.) may yield a mean number of pairs per cave type. A colony size may then be estimated by multiplying the total number of each cave type by the appropriate mean number of pairs and summing them. An alternative, or complementary approach would be to classify the intensity of nocturnal vocalisations at different cliffs or colonies and allocate them to an index of probable nesting population size. Such a method was developed by RATCLIFFE et al. (2000) for Fea's petrels in the Azores. This could be used as a suitable model, given nesting habitat of the two species appears similar and equally inaccessible. On smaller islands with few or no terrestrial predators, petrels may nest in more accessible terrain. In this case, a tape playback methodology may be applied.

Relevant literature: TALEB 2002, RATCLIFFE et al. 2000; [tape playback methodology is described in JAMES & ROBERTSON 1985 for other *Puffinus* species and RATCLIFFE et al. 1998 for small petrels].

Persian shearwater *Puffinus (lherminieri) persicus*

This species has been discovered nesting on Socotra in similar habitat to Jouanin's petrel. The above methods may therefore apply.

Red-billed tropicbird *Phaethon aethereus*

Area: Whole RSGA region.

Habitat and colony type: Dispersed; holes and crevices in cliffs.

Nesting season: Probably April to August, possibly later in Gulf of Aden.

Appropriate methods: Direct counts of occupied holes, but usually can only be detected if bird seen entering or departing. Adults flying around cliffs during the probable nesting season may be an indication of local breeding.

Relevant literature: HANSBRO & SARGEANT 2000; CLAPHAM 1964; NORTH 1946.

Masked booby *Sula dactylatra*

Area: Scarce; southern Red Sea, Gulf of Aden.

Habitat and colony type: Not well described; rocky islands, possibly use trees on occasions.

Nesting season: Summer – autumn?

Appropriate methods: Direct count of nests from air, sea or vantage point.

Relevant literature: MORRIS 1962; NEWTON & AL SUHAIBANY 1996b.

Brown booby *Sula leucogaster*

Area: Widespread, whole RSGA region.

Habitat and colony type: Very varied including sandy beaches and islands, under medium sized bushes, open rocky islands, occasionally cliffs.

Nesting season: Very variable; possibly a prolonged season commencing in summer in the south but with colonies active until January; in north may start earlier (possibly April).

Appropriate methods: Direct counts of nests from air or vantage point. Do not disturb colony during incubation as gulls will rapidly prey upon unguarded eggs.

Relevant literature: NEWTON & AL SUHAIBANY 1996a; HOATH et al. 1997; CLAPHAM 1964.

Socotra cormorant *Phalacrocorax nigrogularis*

Area: Islands off Yemeni coast in Gulf of Aden.

Habitat and colony type: No recent description in Gulf of Aden; usually large dense colonies on sandy or rocky substrate in Arabian Gulf.

Nesting season: In Arabian Gulf, September to April with peak laying October to January.

Appropriate methods: Direct counts of nests from a distance in colonies of size B to low D. For large colonies, high D to E, aerial counts of “apparently occupied nests”.

Relevant literature: SYMENS & WERNER 1996.

Pink-backed pelican *Pelecanus rufescens*

Area: Southern Red Sea.

Habitat and colony type: Usually on top of tall mangroves *Avicennia marina*, occasionally *Rhizophora mucronata*, or lower bushes and exceptionally on the ground.

Nesting season: Winter, possibly November to March.

Appropriate methods: Direct counts from air or aerial photographs, virtually impossible to see nests from ground or sea level.

Relevant literature: NEWTON & SYMENS 1996.

Little green heron *Butorides striatus*

Area: Widespread, whole RSGA region.

Habitat and colony type: Usually concealed in or under dense vegetation (e.g. mangroves) but also in more isolated thickets of *Euphorbia*. Sometimes under nests of other species (such as western reef heron, spoonbill), occasionally in holes and crevices in fossil coral.

Nesting season: Spring, probably commencing in March to April.

Appropriate methods: None known except through searches of dense vegetation; presence/absence possibly only data that can be gathered.

Relevant literature: NEWTON & AL SUHAIBANY 1996a; GOODMAN & MEININGER 1989.

Cattle egret *Bubulcus ibis*

Area: Southern Red Sea.

Habitat and colony type: This species may nest on nearshore islands in tall vegetation; however, it does not utilise the marine environment as a food source.

Nesting season: Throughout the year, perhaps dependent on rains.

Appropriate methods: Direct nest counts of small colonies; aerial counts for large colonies.

Relevant literature: JENNINGS 1995.

Western reef heron *Egretta gularis*

Area: Whole RSGA region.

Habitat and colony type: Usually small to medium colonies (A–B) in dense vegetation, both mangroves and trees, often sub-canopy; occasionally low cliffs.

Nesting season: Spring – summer (March to August).

Appropriate methods: None described; thorough searches on foot of suitable habitat on smaller islands.

Relevant literature: JENNINGS 1995; NEWTON & AL SUHAIBANY 1996a; GOODMAN & MEININGER 1989.

Purple heron *Ardea purpurea*

Area: Local, southern Red Sea.

Habitat and colony type: Probably dense mangrove, unlikely to be colonial, compare JENNINGS 1995.

Nesting season: Not known, possibly spring to summer.

Appropriate methods: None described, thorough searches necessary to prove breeding. Presence outside winter (April to August) may indicate local breeding.

Relevant literature: JENNINGS 1995.

Goliath heron *Ardea goliath*

Area: Local, whole Red Sea.

Habitat and colony type: Usually areas with plenty of mangrove; nests solitarily, sub-canopy or on ground under cover.

Nesting season: Probably winter – spring.

Appropriate methods: Thorough searches necessary to prove breeding.

Relevant literature: NEWTON & AL SUHAIBANY 1996a.

Spoonbill *Platalea leucorodia*

Area: Whole Red Sea, most common in south.

Habitat and colony type: Usually small colonies (B) on top of dense vegetation, both mangroves and thickets, often associated with western reef heron.

Nesting season: Spring – summer.

Appropriate methods: Aerial counts, though ground counts feasible if nesting in thickets of medium height shrubs.

Relevant literature: JENNINGS 1995; NEWTON & AL SUHAIBANY 1996a; EVANS 1989.

Osprey *Pandion haliaetus*

Area: Widespread, whole RSGA region.

Habitat and colony type: Usually well-spaced, large nest structure in open situation, found in all habitats though rarely directly in or on vegetation; occasionally semi-colonial.

Nesting season: Winter (November to April).

Appropriate methods: Easily detectable on ground; aerial counts necessary to get meaningful data from whole archipelago.

Relevant literature: JENNINGS 1995; FISHER 1996.

Sooty falcon *Falco concolor*

Area: Scarce, whole length of Red Sea.

Habitat and colony type: Variable, crevices or caves, on ground under mangroves.

Nesting season: Spring – summer.

Appropriate methods: Pairs usually flushed if landings made on island; usually detectable by aerial survey.

Relevant literature: GAUCHER et al. 1995.

Crab plover *Dromas ardeola*

Area: Local along length of Red Sea.

Habitat and colony type: Nests underground in burrows; in colonies (B–C) on sandy islands.

Nesting season: Summer (commencing May/June).

Appropriate methods: Colonies can be quite easy to overlook; direct counts of burrows straightforward but not easy to prove occupancy. If possible, do not walk through colony, as burrows are very easy to collapse.

Relevant literature: GOLDSPINK et al. 1995; NIKOLAUS 1987; MORRIS 1992.

Kentish plover *Charadrius alexandrinus*

Area: Widespread, probably whole RSGA region.

Habitat and colony type: Dispersed nests on open shore just above high water mark in seaweed, flotsam or broken coral rubble.

Nesting season: Spring, mostly February to May.

Appropriate methods: Nests difficult to find, but adults frequently employ distraction displays that are sufficient proof of breeding.

Relevant literature: JENNINGS 1995.

Sooty gull *Larus hemprichii*

Area: Widespread, probably whole RSGA region.

Habitat and colony type: Dispersed or loose colonies on both sandy and rocky islands. Nests usually in shade of rock or small bush.

Nesting season: Commences April/May in north, June/July in south.

Appropriate methods: Flush counts of adults emerging from nests can be made from air; loose colonies usually small, so nests can be counted directly during ground work.

Relevant literature: JENNINGS 1995; NIKOLAUS 1987; GOODMAN & MEININGER 1989; NEWTON & AL SUHAIBANY 1996a.

White-eyed gull *Larus leucophthalmus*

Area: Widespread, probably whole of RSGA region.

Habitat and colony type: Small colonies (B), often in open sand, occasionally more rocky substrate.

Nesting season: Summer, probably commences June in north and July in south.

Appropriate methods: As for sooty gull.

Relevant literature: As for sooty gull.

Caspian tern *Sterna caspia*

Area: Widespread but scarce, probably whole of RSGA region.

Habitat and colony type: Solitary or dispersed loose colonies, usually fairly open sandy areas. Occasionally nests on mainland coasts, e.g. sand-spits.

Nesting season: Spring, usually February to April/May.

Appropriate methods: Nests can be detected from air if few other species present; otherwise detailed groundwork is needed.

Relevant literature: JENNINGS 1995.

Swift and lesser-crested tern *Sterna bergii, S. bengalensis*

Area: Widespread, whole of RSGA region.

Habitat and colony type: Large dense colonies of both species often found side by side; often on edge of larger sandy islands or more centrally on smaller ones.

Nesting season: Summer, usually June to August, swift terns possibly earlier than lesser-crested terns.

Appropriate methods: Aerial counts can yield acceptable estimates of numbers of individuals and nests; photographs could be useful for more accurate counts. Otherwise, nest density needs to be measured in sample quadrats or belt transects and extrapolated to measured/estimated area covered by colony.

Relevant literature: SYMENS & AL SUHAIBANY 1996; SYMENS & EVANS 1993; NEWTON & AL SUHAIBANY 1996a; MOORE & BALZAROTTI 1983.

White-cheeked tern *Sterna repressa*

Area: Common and widespread, whole of RSGA region.

Habitat and colony type: Usually medium sized (B to low C) colonies, frequently in open sandy areas or coral rubble; may be several discrete sub-colonies even on quite small islands.
Nesting season: Summer, usually June to August.

Appropriate methods: Often difficult to detect during aerial counts as colonies are amongst larger numbers of bridled terns or brown noddies. However, the number of nests can usually be counted by two or more observers walking in parallel through a colony. Care should be taken not to trample eggs, as nests can be quite cryptic. Flush counts of adults attending nests are satisfactory if time limited.

Relevant literature: As swift tern, SIMMONS 1994.

Bridled tern *Sterna anaethetus*

Area: Common and widespread, whole RSGA region.

Habitat and colony type: Colonies will often stretch over whole islands with moderate to dense vegetation cover. Nests fairly well dispersed under bushes (although there may be more than one nest under any one bush) or small rocky overhangs.

Nesting season: Summer, usually May/June to August.

Appropriate methods: Numbers of adults flushed from nests can be estimated during aerial counts. On the ground, counts of adults perched on bushes following flushing during the incubation period may give approximation of numbers of pairs. If more detail required, then sample quadrats or belt transects are necessary. Make sure sampling covers the range of vegetation types, bush densities and heights.

Relevant literature: As for swift tern, SWEET 1994.

Sooty tern *Sterna fuscata*

Area: Occasionally recorded breeding on the African coastline of the Gulf of Aden.

Habitat and colony type: In other parts of the world, nests in the open in very large dense colonies similar to swift and lesser-crested terns. However, colonies in RSGA region probably relatively small.

Nesting season: Possibly June

Appropriate methods: Detailed methodology given in paper below.

Relevant Literature: RATCLIFFE et al. 1999.

Saunder's tern *Sterna saundersi*

Area: Widespread but local on Arabian side of the Red Sea, apparently scarcer on the African side.

Habitat and colony type: Small loose colonies (A–B) in sandy areas; may nest on mainland coasts.

Nesting season: Spring, first eggs usually April.

Appropriate methods: Very seldom detected during aerial surveys; detailed ground work needed to prove presence of nests.

Relevant literature: JENNINGS 1995.

Brown noddy *Anous stolidus*

Area: Widespread, southern Red Sea and Gulf of Aden, usually on islands well offshore (>20 km).

Habitat and colony type: Colonies usually large (C–D) on well-vegetated islands often covered with *Suaeda fruticosa*; rarely mangrove *Avicennia marina*. Nests sub-canopy on branches of trees or bushes.

Nesting season: Probably summer, May to August.

Appropriate methods: Several aircraft overpasses usually flush adults from vegetation, although some adults may remain *in situ*. However, aerial counts are probably easier to undertake than ground counts, as it is very difficult to count nests in dense vegetation. More validation work urgently required on this species.

Relevant literature: MOORE & BALZAROTTI 1983; NEWTON & AL SUHAIBANY 1996a.

8.3 DATA ANALYSIS AND PRESENTATION

All field data should be transcribed onto clean sheets as soon as possible after surveys are completed, then entered into EXCEL spreadsheets on return to base camp. Two formats can be used; the first covering information on the islands themselves, and a second giving bird and nest counts (see Appendix 8.5.1). Suggested formats are provided below.

The island and bird spreadsheets can be copied into a relational database such as ORACLE or MICROSOFT ACCESS. Linked and composite tables can then be generated and analysed. The data can then be imported into a mapping package (e.g. DMAP or a GIS such as ARCVIEW).

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Notes: The island database (Appendix 8.5.1.A) lists all the background information collected from the islands visited. Definitions of habitat variables and other parameters used in the spreadsheets are given below:

No. isles: number of islands included in count unit.

Code No.: sector reference (A–G) followed by unique number.

Size: A: 50-500 m (longest axis); B: 501–5,000 m (longest axis); C: >5,000 m (longest axis).

% Sand: percentage of island surface (above high water mark) covered by soft substrates: sand, silt, mud, loose soil; includes most land covered in mangroves.

% Rock: percentage of island surface (above high water mark) with hard substrate: coral rock, volcanic rock, and boulders.

% Veg: percentage of island surface covered by vegetation: mangroves, bushes and shrubs, graminoids.

Veg.Ht: 0 = mangrove or sand and rock only; 1 = low bushes (<1 m) and graminoids; 2 = tall bushes, shrubs and trees (>1 m, but usually 2–3 m).

Mangr: 0 = none; 1 = 1–33% of surface area covered by mangroves; 2 = 34–66% of surface area covered by mangroves; 3 = 67–100% of surface area covered by mangroves.

Relief: 0 = flat; 1 = undulating or some low cliffs or dunes; 2 = relatively mountainous.

Huts: number of fishing camps/shelters present on the island (R = ruins/remains, CGS = coastguard station).

Boats: number of boats on or within 2 km of island; primarily refers to fishing boats but also includes dhows, larger vessels and coastguard boats at sea.

ID: location reference used on field maps and recording forms, which may be different from final code number.

Alt. name/Notes: other names for island or nearest named landmark on maps available. Also record other information such as the presence of turtle pits.

Appendix 8.5.1 Examples of spreadsheets for (A) islands and (B) birds.

Code No.	Name	Northing	Easting	No. isles	Size	%Sand	%Rock	%Veg	Veg.Ht	Mangr	Relief	Date	Huts	Boats	ID	Alt. Name/Notes
B 96	Matbakhayn	17 28	41 47.5	3	1	0	100	0	0	0	1	01-Jun	R		3	
B 97	Wasaliyat S.	17 40	41 01.5	1	1	100	0	0	0	0	0	12-Jun			1	
B 98	Wasaliyat N.	17 41	41 01.5	1	1	100	0	0	0	0	0	12-Jun			2	
B 99	Sumayr	17 47	41 25.5	1	2	95	5	90	2	0	0	01-Jun			2	
B 100	Zahrat Sumayr	17 49.5	41 10	1	1	95	5	0	0	0	0	12-Jun			3	
B 101	Kutambil	17 53	41 41	1	2	30	70	4	1	0	2	05-Jul			1	
B 102	J. al Aqamah S.	18 01.5	41 36	1	1	100	0	0	0	0	0	05-Jul			2	Khawr Wasm
B 103	J. al Aqamah NW	18 03	41 34	1	2	100	0	60	1	0	0	05-Jul	1		3	Khawr Wasm
B 104	J. al Aqamah NE	18 03.5	41 35	1	1	100	0	0	0	0	0	05-Jul			4	Khawr Wasm
B 105	J. Hasr	18 09	41 32	1	2	100	0	50	1	1	0	05-Jul			5	
B 106	J. ad Durayqi	18 16.5	41 29	1	1	100	0	0	0	0	0	05-Jul			6	Khawr Nahud
B 107	Marka	18 14	41 19.5	1	2	100	0	100	2	0	0	01-Jun	1		1	
B 108	Zuqaq E.	18 03	41 00	1	1	100	0	0	0	0	0	12-Jun			4	
B 109	Zuqaq SE	18 02	40 57	1	1	100	0	0	0	0	0	12-Jun			5	J. Miraya
B 110	Zuqaq SW	18 01.5	40 49	1	1	50	50	0	0	0	0	12-Jun			6	
B 111	Zuqaq W.	18 04	40 47	1	1	95	5	0	0	0	0	12-Jun			7	J. Zuqaq
B 112		18 09	40 49	1	1	100	0	0	0	0	0	12-Jun			8	
B 113		18 14.5	40 53	1	1	100	0	100	2	0	0	29-Jun			9	
B 113A		18 18	40 55	1	1	100	0	0	0	0	0	29-Jun		2		no count
B 114	Al Umm S.	18 13	40 43.5	1	1	50	50	0	0	0	0	12-Jun			9	
B 115	Al Umm central	18 15	40 44	1	1	100	0	100	2	0	0	12-Jun			10	
B 116	Al Umm E.	18 16	40 45.5	1	1	100	0	100	2	0	0	12-Jun			11	
B 117	Al Umm N.	18 16.5	40 44	1	1	100	0	100	2	0	0	12-Jun			12	

(A) An example of an island spreadsheet for a section of the Saudi Arabian Red Sea coast.

Island Number	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	Total
Species																							
Red-billed tropicbird	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brown booby	40	40	200	60	150	40	0	0	3	0	0	300	25	20	0	25	2	160	15	200	50	100	1430
Brown booby nests	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pink-backed pelican	0	0	0	8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	10
Little green heron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cattle egret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cattle egret nest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Western reef heron	0	0	0	1	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	13
Western reef heron nests	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gray heron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Purple heron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Goliath heron	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Spoonbill	0	0	0	0	0	8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	9
Spoonbill nests	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Osprey	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	1	0	0	0	1	5
Sooty falcon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crab plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sooty gull	0	0	0	0	0	60	0	70	0	100	25	0	0	0	0	0	0	0	0	0	0	0	255
White-eyed gull	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Gulls	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Caspian tern	0	0	0	0	0	0	0	0	6	0	0	0	1	0	0	0	0	0	0	0	2	0	9
Swift tern	10	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	310
Swift tern nests	0	0	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
Lesser-crested tern	0	200	300	0	40	0	40	0	0	40	0	300	0	10	0	150	15	0	0	0	0	0	1095
Lesser-crested tern nests	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300
White-cheeked tern	0	0	0	0	0	0	0	0	0	200	120	0	0	0	0	0	0	0	0	0	0	0	320
Bridled tern	0	0	0	200	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	100	75	150	575
Saunder's little tern	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Terns	0	0	0	10	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	15
Brown noddy	0	0	0	630	0	0	0	0	0	0	0	400	0	0	15	40	5	20	0	700	500	1000	3310

(B) Bird Spreadsheet.

An example from an aerial survey of the Saudi Arabian Red Sea coast is given below. Separate EXCEL spreadsheets can be created for aerial and ground counts.

9

MARINE MAMMALS

9.1 INTRODUCTION

The marine mammal fauna of the Red Sea and Gulf of Aden is not well known. Although 44 species of cetacean (dolphins, porpoises and whales) and one species of sea cow (the dugong) are known from the Indian Ocean, only 15 species have been reported from the Gulf of Aden and 11 from the Red Sea (Table 9.1). However, the species list for the Red Sea is known to be incomplete. No baleen whales have been reported for the Red Sea, yet three whales (suspected of being Bryde's) were seen on each of two aerial surveys of the Farasan Islands area (in August 1987 and September 1993; PREEN unpublished data). The fact that these whales appear to be common in the southern Red Sea, but have never been reported, demonstrates the need for more survey work.

Of the 16 species of marine mammal confirmed from this region, three are listed as threatened species (endangered or vulnerable), five are considered dependent upon specific conservation efforts to prevent threatened listing, five are insufficiently known to ascribe any status and three are considered secure (IUCN 1996; Table 9.1). These figures highlight the need for more information on the marine mammals of this region. Only with data on distribution, abundance and threats can effective management be implemented for the conservation of this important group of animals.

Worldwide, cetaceans and dugongs face many threats. While the large whales still suffer from legal and illegal whaling operations, a more insidious and widespread threat is posed by mesh nets, which are predominately used to catch fish. In recent decades the proliferation of synthetic gill nets throughout the world has posed a serious threat to some cetaceans, dugongs, seabirds, turtles and fish. In 1990, six stocks of cetaceans were identified as suffering unsustainable mortality in net fisheries (COOKE 1991). Sanctuary areas, where mesh-nets are banned, have been established to protect threatened populations of dugongs (e.g. eastern Australia; DPI 1998; PREEN & MORISSETTE 1997) and some small cetaceans (e.g. Banks Peninsula, New Zealand, DAWSON & SLOOTEN 1993; upper Gulf of California, Mexico, REEVES & LEATHERWOOD 1994). Marine pollution by oil or other chemicals is an ever-present threat. Although the evidence for a link between chemical pollution and the health of marine mammal populations remains largely circumstantial, there is growing concern that large contaminant loads can increase susceptibility to disease and affect reproduction. Disturbances from shipping, military activities (e.g. target practice, depth-charge practice), seismic exploration for oil, and increased boating activity have also been identified as potential threats to marine mammals (COOKE 1991; FRAZIER et al. 1987).

Species		IUCN status	Distribution & Reference		Rarity 1=more common 2=less common
			GA	RS	
Dugong	*Dugong dugon*	VU	1	5	1
Blue whale	*Balaenoptera musculus*	EN	2,4		2
Bryde's whale	*Balaenoptera edeni*	DD	2		1
Sperm whale	*Physeter macrocephalus*	VU	2,4		1
Melon-headed whale	*Peponocephala electra*		2		2
False killer whale	*Pseudorca crassidens*		2	3,4	2
Killer whale	*Orcinus orca*	CD	2	4	2
Short-finned pilot whale	*Globicephala macrorhynchus*	CD	2,4		1
Indo-Pacific humpbacked dolphin	*Sousa chinensis*	DD	2	3,4	1
Common dolphin	*Delphinus delphis*		2	4	1
Bottlenose dolphin	*Tursiops truncatus*	DD	2	3,4	1
Risso's dolphin	*Grampus griseus*	DD	2	3,4	1
Pantropical spotted dolphin	*Stenella attenuata*	CD	2	3,4	1
Striped dolphin	*Stenella coeruleoalba*	CD	2	4	2
Spinner dolphin	*Stenella longirostris*	CD	2	4	1
Rough-toothed dolphin	*Steno bredanensis*	DD		4	2

1. ROBINEAU & ROSE 1982. 2. SMALL & SMALL 1991. 3. BEARDON 1991. 4. FRAZIER et al. 1987. 5. PREEN 1989.

Table 9.1 Species of marine mammal reported from the Red Sea (RS) and Gulf of Aden (GA), and their conservation status. IUCN (1996) categories: EN: endangered; VU: vulnerable; CD: conservation dependent; DD: data deficient.

There is little specific information about threats facing marine mammals in the Red Sea and Gulf of Aden. Perhaps most is known about the dugongs, at least along the eastern coast of the Red Sea (Saudi Arabia and Yemen). In 1987, the dugongs in this area were censused by large scale aerial surveys, and fishermen were interviewed to learn about threats to the dugongs (PREEN 1989). That study estimated there was a population of 2000 dugongs in the eastern Red Sea and that the level of fish-net related mortality of dugongs was low in most areas. The one area where net mortality levels may have been unsustainable (the Gizan and Farasan Islands area) was resurveyed in 1993 and the results suggested a decline in dugong numbers (PREEN unpublished data). Very little is known about the dugong populations along the western shore of the Red Sea or in the Gulf of Aden. Even less is known about most species of cetacean. There is a genuine need for marine mammal surveys to be conducted in this region before it will be possible to make confident statements about the status of any species.

9.1.1 Surveying marine mammals

Marine mammals are highly mobile and move over very large areas. Even species thought to be relatively sedentary, such as dugongs, can be highly mobile. Satellite-tracked dugongs have moved between areas up to 700 km apart over a two-week period (PREEN 2000). Furthermore, marine mammals are rare compared with most marine life. Consequently, surveys of marine mammals must cover large areas and must expect only a low rate of encounter. The need to cover large areas often means that surveys are expensive to conduct. The low sighting rate has implications for the accuracy and precision of population estimates derived from the surveys and a comparatively high coefficient of variation of the result can generally be expected. Because of the difficulties involved in properly surveying marine mammals, it is important to clarify the objectives of the survey, to reconcile these with the resources available and to select the most appropriate method.

9.1.2 Survey objectives

In a region like the Red Sea and Gulf of Aden, where there is relatively little existing information, the objectives of any surveys should reflect the information needs.

The most basic needs for informed management are:

- A list of the species present
- The broad distribution of each species
- Some measure of the abundance of each species
- The particular habitat requirements of each species, and
- The main causes of mortality or threats to the marine mammals in the region.

Measurement of abundance can be difficult. Two measures are used: absolute abundance and relative abundance. The absolute or actual abundance can be very expensive to determine accurately. Relative abundance, by contrast, is an index that reflects actual abundance. Many survey methods that have the potential to measure absolute abundance really measure relative abundance. This occurs when accurate detection functions and correction factors, which are necessary to correct for animals that are deep below the surface and are undetectable, have not been derived. This is generally not a problem as good measures of relative abundance are adequate for most purposes. Good data on relative abundance will allow the monitoring of the size of a population through time (as long as the repeated surveys exactly duplicate the previous surveys).

9.1.2 Available resources

The realistic objectives of a survey and the selection of the most appropriate survey method will be dictated largely by the skills and training of the researchers, the facilities available and the size of the budget. Generally, the methods that provide the most quantitative data are sophisticated and expensive to implement properly. Furthermore, they require substantial logistic support and high levels of training.

9.1.3 Selection of methods

There are many survey methods, ranging from the simple to the highly sophisticated, from the inexpensive to the very expensive. Table 9.2 provides an incomplete list of methods with an indication of the type of information they can provide and the resources they require. It is important to realise that there is no single best technique (ARAGONES et al. 1997). Different methods will be appropriate to different surveys, depending on their objectives and the resources that are available.

Method	Information provided	Spatial scale	Technical requirements	Cost
Interview survey	Distribution, relative abundance, habitat preferences, most important areas, mortality factors, population trends	large area	low	low
Carcass salvage	Species list, unusual causes of mortality, seasonality of mortality, aspects of biology (age, diet, reproductive history, genetics)	limited area	low to high	low to high
Transect boat surveys	Species list, distribution, relative abundance, absolute abundance (with adequate correction factors), monitoring abundance through time, human activities in the study area	medium area	medium	medium
Shoreline aerial surveys	'Hot spot' areas for coastal marine mammals, distribution of species, distribution of habitats, human activities in the study area	large area	low	medium
Transect aerial surveys	Distribution, relative abundance, absolute abundance (with adequate correction factors), monitoring abundance through time, use of different habitats, extent of preferred habitats	large areas	high	high

Table 9.2 Summary of the attributes of the main survey methods for marine mammals.

9.2 METHODOLOGY

9.2.1 Interview Surveys

Introduction

Interview surveys are a useful and inexpensive first step in establishing a database of marine mammals for a region. Fishermen, and other knowledgeable people, can be interviewed to learn from their experiences with the various species present in the region. When working in an area where little information exists, interview surveys can provide the most information for the least expense. Interview surveys can identify particularly important areas for marine mammals. They may also be used to evaluate the conservation interest of local people and for initial education. Subsequent repeat surveys can assess the impact of education or conservation projects. Interview surveys are most useful for inshore species, such as dugongs and some species of dolphin, with which people are most likely to interact. Because they are inexpensive to implement, interviews can be conducted along extensive sections of coastline, thus providing regional data.

Information that can be obtained

Interview surveys can provide information on the distribution of species and subjective data on their relative abundance. They may also provide subjective views of trends in abundance over years to decades. Interview surveys can provide information on the sources and levels of mortality, on hunting and capture methods, and on uses made of the animals. Information on habitat preferences, aspects of biology (such as movement patterns, breeding season, and food) may also be provided. Awareness of conservation efforts and relevant laws may also be evaluated.

Expertise needed

Some knowledge of interview techniques and questionnaire design is required. Good interpersonal skills and fluency in the local language, or the aid of a good translator, is essential. Knowledge of the people to be interviewed and their culture is important. The interviewer must also have a good knowledge of the marine mammals that may occur in the area.

Equipment needed

A vehicle would be required to move from settlement to settlement along the coast. A collection of laminated photographs of the animals expected in the area (and some that could not be in the region) is very useful.

Costs

There are few expenses other than salaries and the cost of transport.

Method

Interviews can be formal or informal. An informal, semi-structured approach, where the interview can take place as a directed conversation is often most successful when there are only a few knowledgeable people. This approach may also be best if the interviewers may be perceived as representatives of the government, and a level of suspicion and intimidation has to be overcome. Good rapport must be established before the interview is conducted. This may take some time. Interviews cannot be rushed and must develop and proceed at a rate that the informant is comfortable with. Some fishermen are particularly observant and knowledgeable. When such fishermen are encountered it may be desirable to extend the relationship with the informant(s) over several visits.

Following initial formalities and the development of trust, interviews should usually start with a series of descriptive questions, where the informant is encouraged to describe what he has observed or learned. These questions can lead to more structured questions, where the informant is asked to provide detailed information about particular areas of interest and knowledge. The interview must also include a range of contrast questions. These aim to check the reliability of the informant, and therefore the validity of the information he is providing. Contrast questions may include queries to which the answers are already known, as well as questions to which the informant could not possibly know the answer (e.g. life history data that can only be derived by scientific techniques).

It can be very helpful to have photographs of the different marine mammals that may occur in the area. It should be noted that the identification of some dolphins is very difficult and some identifications made by informants may not be accurate. Inclusion of photos of some distinctive species that do not occur in the region can be useful for assessing the reliability of species identifications. Skull bones (or photographs of them) can also be helpful in stimulating conversation and establishing rapport. It is common for there to be skull bones of whales, dugongs or dolphins in fishing villages. These should be photographed and identified where possible.

Appendix 9.6.1 lists the type of information sought from fishermen in Saudi Arabia and Yemen to help assess status of dugongs along the eastern Red Sea (PREEN 1989). That study also included detailed aerial surveys to estimate the numbers of dugongs in the region. Consequently, the interviews focussed on the numbers of dugongs killed in nets or by hunting.

In areas where there is a high level of human activity in the coastal waters, such as around coastal cites, sighting sheets can be used to collect information about marine mammals. An example of a sheet that could be adapted for use in the region is included in Appendix 9.6.2. Such sheets can be distributed to people who regularly spend time in boats in the area of interest. The information provided is often of limited use due to the unreliability of the identifications, and the non-random sampling effort. However, when used with other survey methods which may verify the data provided, sighting sheets can provide useful supplementary information on distribution and group sizes. Moreover, such sighting sheets are very useful in increasing public awareness of marine mammals.

A set of outline drawings of the marine mammals listed in Table 9.1, together with a sketch of their skulls, is provided in Appendix 9.6.3. These may prove useful for the identification of live or dead specimens. Readily available guides to the identification of cetaceans include JEFFERSON et al. (1993) and LEATHERWOOD & REEVES (1983).

9.2.2 Carcass Salvage

Introduction

Marine mammals that wash up on beaches can be a useful source of information. Beaches can be driven or walked in search of beached carcasses or old skeletal material. In more populated areas local people can be encouraged to report carcasses. A carcass salvage programme can be simple and inexpensive or sophisticated and expensive, depending on its aims and the facilities and expertise available. Carcass salvage is often unpleasant work as the animal has often been dead for a period of time. Despite the unpleasantness, carcass salvage is important work.

Information that can be obtained

At the most basic level, carcasses of marine mammals provide evidence for the presence of the species in the region. Although species identification may be easiest with recently dead carcasses, old skulls found high on the beach can also be identified and DNA can be extracted from dried skin (and perhaps even old bones) to determine identification. Carcasses of marine mammals can also provide information on the causes and rates of mortality of species (e.g. if they are dying in nets the carcasses sometimes retain characteristic marks). Repeated surveys of long stretches of coast conducted at yearly intervals may provide information on the normal rate of mortality in the region, and thus may highlight any unusual increases. Surveys repeated more frequently over smaller sections of coast can identify any seasonal patterns in mortality (sometimes such peaks in beached carcasses relate to certain types of seasonal fishing activity). If facilities and training are available, freshly dead carcasses can provide samples that can be analysed to provide information on the biology of the species (e.g. age, age of sexual maturity, fecundity, season of mating and birthing, diet, genetics). Tissues can also be analysed for levels of pollutants, parasites and pathogens.

Expertise needed

The ability to identify the marine mammal species of the area and knowledge of their basic anatomy is required. Experience of necropsy procedures and techniques for the proper collection and preservation of specific tissue samples is also highly desirable. Such samples can be sent to specialists for analysis if local facilities and expertise are unavailable.

Equipment needed

A four-wheel drive vehicle with appropriate safety and self-rescue gear is required for travel along beaches. Suitable maps and a GPS to record the location of specimens should be used. A necropsy kit should contain a range of surgical gear from large knives to scalpels, plastic bags, containers and labels for samples, a measuring tape, a camera, gloves and clean-up materials. Caution should be taken not to cut yourself, especially when dealing with rotting carcasses. The necropsy kit should include appropriate data sheets and a simple guide to the identification of marine mammals in the region (Appendix 9.6.4).

Costs

Implemented at its basic level, carcass salvage is inexpensive as the main costs are salaries and transportation. Analysis of tissue samples can be expensive.

Method

The fresher the carcass the more information can be collected. An extremely fresh carcass (hours old, depending on ambient temperature) can provide samples and data that give information on bacteriology, virology, haematology and pathology. However, there is little need for such information until a great deal is already known about the populations of marine mammals in the region and the threats they face. Moreover, the skills required and the expense involved for the collection, analysis and interpretation of this type of information are considerable.

A carcass that is hours to days old may provide information on parasites, contaminants (by analysis of tissue samples), cause of death (from marks on the body), diet (by analysis of stomach contents), age (by analysis of growth layers in the teeth), gender, reproductive stage (by examination of gonads and reproductive tract) and genetics (by analysis of skin or gonad samples). Some of these analyses require special expertise or experience. However, most of the samples can be collected and preserved by someone with a good knowledge of the anatomy of cetaceans and dugongs, and basic necropsy training.

Even a rotten carcass that has been dead for days to weeks can provide data on species present (identification based on measurements of the extracted and cleaned skull), age, body length and genetics. Sometimes it is still possible to determine the gender of the animal, and in the case of dugongs the stomach contents may still be intact. As the carcass ages further only the skull and perhaps a piece of dried skin can be collected. Even these samples can allow the carcass to be identified to species, aged, and its genetic data to be determined.

GERACI & LOUNSBURY (1993) provide a detailed guide to the anatomy and sampling of marine mammal carcasses. A detailed manual for the necropsy of dugongs can be downloaded from <www.gbrmpa.gov.au/corp_site/info_services/publications/research_publications/rp64/index.html>. Much of the information in this manual is applicable to cetaceans. Appendix 9.6.4 includes a simple identification guide and a data sheet for recording basic information from a carcass in English or Arabic (PREEN et al. 1989). Appendix 9.6.5 contains a detailed data sheet for the recording of full morphometric data from cetacean carcasses. Appendix 9.6.6 is a data sheet specifically for dugongs that can help guide the necropsy and be a reminder of the samples to collect. Ideally samples and data should be lodged with national museums where they can be professionally stored and kept for future reference and study.

9.2.3 Line-Transect Boat Surveys

Introduction

A boat with an elevated viewing platform follows a predetermined path and observers search each side and in front of the boat for marine mammals. Once sighted, the distance to each group and the angle of each group from the transect is recorded, along with information about the number and species of marine mammals in the group.

Information that can be obtained

Boat surveys can provide quantitative information on the abundance and distribution of cetaceans at the species level over large areas. When repeated regularly in an area, these surveys can identify seasonal distribution and movement patterns. Repeated surveys can also be used to monitor changes in the abundance of species over time. Because a lot of time is spent on the water, this method can provide insights into conservation issues in the area. Boat surveys are not effective for surveying dugongs as this species spends very little time near the surface. Boat surveys are effective for surveying large cetaceans only if the whales are very common in the region, or the surveys cover very large areas extending long distances from the coast. Generally, such surveys require large ocean-going vessels, and are very expensive to conduct.

Expertise needed

This method requires trained observers that can identify cetaceans confidently. The design of surveys and the analysis of the data requires a high level of training, including knowledge of line transect methodology, statistical skills and access to appropriate software.

Equipment needed

A suitable vessel is required with a depth sounder, GPS (often present as part of the vessel's navigation equipment), binoculars, sighting compass, data sheets, charts, computer and software.

Costs

Boat time can be expensive, although it is possible to conduct these surveys on small local craft if a suitable platform can be erected and the seas are calm. The associated equipment can also be expensive. Several observers are required to search either side of the boat thoroughly and allow for rest periods to reduce fatigue.

Method

The survey should be designed to cover the entire survey area and the transect lines should be random with respect to marine mammal distribution. If a relatively small boat is used it may be necessary to design the transects to allow the boat to be in a port each night. The density of the survey lines will depend on the size of the area to be surveyed. Detailed surveys of relatively small areas, which seek to determine fine-scale distribution, may have transects as close as 1 km apart (e.g. JEFFERSON & LEATHERWOOD 1997). In regional surveys, covering thousands of square kilometres, transects may be 5–20 km apart (e.g. DOLAR et al. 1997).

The size of the boat used for a line transect survey will depend on the extent to which the survey covers offshore waters, where conditions may become rough. Higher observation platforms are more likely on larger boats. Observers should be at least 3 m above water level. Boat speed while on-transect should be about 7–8 knots (kn) (13–15 km/h).

Marine mammals can be difficult to identify, so the spotting team must include at least some trained observers. A minimal survey team would consist of two trained observers. One observer would continuously search the path in front of the boat (from 9 o'clock to 3 o'clock if the boat is assumed to be pointing to 12 on a clock face) with binoculars (7 x or 8 x). The other observer would search for animals directly on the boat path with the naked eye (to assure optimal compliance with assumption 1, below), and acts as data recorder for the primary observer. A larger team would have four observation positions, a data recorder, and a rest station. Position 1 would search the transect in front of the boat from 9 o'clock to 3 o'clock using powerful binoculars (up to 20 x) that may be mounted on the deck. Positions 2 and 3 would be located on each side of the viewing platform and search 9 o'clock to 12 o'clock and 3 o'clock to 12 o'clock, respectively, using 7 x or 8 x binoculars. The observer in position 4 would search the transect directly in front of the boat with the naked eye.

When a sighting is made, the boat may be stopped and the following information recorded:

- Time, position (from GPS)
- Sighting angle (the angle between the compass bearing to the group and the compass bearing of the transect)
- Sighting distance
- Group size
- Associated animals
- Notes on interesting behaviours and
- Basic oceanographic data (e.g. water temperature, salinity and depth).

The sighting data should be recorded in a standardized format (see Appendix 9.6.7). A GPS can provide vessel path and speed. Periodically (e.g. every 15 min.) sighting conditions (Beaufort sea state, visibility) should also be recorded. Sighting distance may be estimated by eye after training. It may be checked by taking a GPS point from the position in which the animals were first seen and comparing this to the boat's position at the time of the initial sighting. Sighting angles can be measured with binoculars with an inbuilt compass or a good sighting compass could be used. Observations should only be made under relatively good conditions, that is, Beaufort sea state ≤4 (Table 9.3).

Data analysis

Line-transect methods use the information on the distribution of perpendicular sighting distances and the amount of survey effort to estimate density and abundance. This methodology requires that a series of assumptions are met if unbiased abundance estimates are to be obtained (BURNHAM et al. 1980). The main assumptions are:

- All groups actually on the transect are detected. This is unlikely to be met with cetaceans and dugongs and will result in negative bias in abundance estimates. Detection functions have been developed for some species to correct for missed groups (BUCKLAND et al. 1993) and some surveys have towed cetacean detectors behind the boat to determine the proportion of some species that are missed by the observers (JEFFERSON 2000). In most situations, however, it is a matter of diligent observation to ensure minimal violation of this assumption.
- Animals are observed and recorded before they move in response to the boat.
- Sightings are independent of each other.
- The average group size for each species is estimated without bias.
- Sighting angles and distances are measured accurately.

Beaufort value	Description of wind	Sea conditions	Wind speed (knots)	Wave height (cm)
0	Calm	Smooth, mirror-like	0-1	0
1	Light air	Scale-like ripples	1-3	7
2	Light breeze	Small short waves, crests have glassy appearance and do not break	4-6	15
3	Gentle breeze	Large wavelets; some crests begin to break; foam of glassy appearance; occasional white foam crests	7-10	60
4	Moderate breeze	Small waves, becoming longer; frequent white foam crests (‘white horses’)	11-16	120
5	Fresh breeze	Moderate waves taking a more pronounced long form; many ‘white horses’, there may be some spray	17-21	200

Table 9.3 Abbreviated Beaufort scale for ranking sea state and estimating wind speed.

Perpendicular sighting distance is calculated from the sighting distance and sighting angle using the formula:

$$y = r \sin \varphi$$

where

y = perpendicular sighting distance

r = sighting distance

φ = sighting angle

Density and abundance, and their associated coefficients of variation are estimated using the following formulae:

$$D = [n\, f(0)\, E(s)] \,/\, 2L$$

$$N = [n\, f(0)\, E(s)\, A] \,/\, 2L$$

$$CV = \sqrt{\{[\mathrm{var}\,(n) / n^2] + [\mathrm{var}\,(f(0)) / (f(0))^2] + [\mathrm{var}\,(E(s)) / (E(s))^2]\}}$$

where:

D = individual density

n = number of sightings

$f(0)$ = value of the probability density function

$E(s)$ = mean group size

L = length of transect surveyed

N = individual abundance

A = size of the study area

CV = coefficient of variation

var = variance

The calculation of $f(0)$ requires complicated mathematics and statistics. A computer programme called DISTANCE (LAAKE et al. 1994) is available to derive $f(0)$ and the estimates of density and abundance. It is recommended (BUCKLAND et al. 1993) that the perpendicular distance is truncated at a certain distance to remove outliers, improve the modelling and reduce the coefficients of variation. Typically only the most distant 2–3% of sightings are removed.

9.2.4 Shoreline Aerial Surveys

Introduction

This is a relatively simple and inexpensive method of identifying some of the most important habitats for inshore species, particularly dugongs. A light aircraft is flown at low altitude over near-shore waters and the location and number of marine mammal groups, and the habitat in which they are seen is recorded onto maps. The flight path usually searches areas that are expected (on the basis of information from interview surveys or other sources) to be suitable for dugongs or inshore cetaceans.

Information that can be obtained

This method can identify 'hot spot' areas where marine mammals are common and can give the researchers a good appreciation of the distribution of habitat types in the region. Information on the distribution of turtles, seabirds and human activities (e.g. fishing, location of villages, location of coastal developments, etc.) can be collected at the same time. Frequently repeated surveys may provide information on the seasonality of occurrence of species in a region. However such data should be treated cautiously and as preliminary, as such a very small proportion of the sea surface in an area is actually searched during shoreline surveys (consequently, the absence of evidence is not necessarily the evidence of absence).

Expertise needed

The identification of marine mammals from the air can be difficult and considerable experience is required to get reliable identifications. Basic cartographic skills are required for designing the flight path and the accurate plotting of sightings.

Equipment needed

Maps and binoculars are essential. To reduce the effects of aircraft vibration, binoculars should not be too strong (≤8 x) and should have a large-diameter lens near the eye. A camera is highly desirable. A GPS can be helpful, but is not essential as it is usually possible to navigate accurately from coastal features.

Costs

The charter of the aircraft and pilot is the main expense. However, large areas can be covered in a relatively short period, usually making this method cost-effective.

Method

A helicopter or high-wing aeroplane (for an unimpeded view of water) can be used; the former is more expensive to operate. A single-engined aircraft is suitable as the aircraft is rarely far from land. The aircraft is typically flown at an altitude of about 700 ft (400–900 ft; 122–274 m) at a ground speed of 90–100 kn (167–185 km/h). Good survey conditions are required for high sighting rates: low cloud cover, surface wind ≤15 kn (28 km/h; Beaufort sea state ≤3). Water clarity can vary with season (depending on direction and strength of wind as well as rainfall/run-off events) and surveys are best conducted when the water is clearest. Observers should wear polarized sunglasses to minimise the effects of reflected glare.

Fuel availability can be an important logistical constraint in some areas. It may be necessary to arrange fuel dumps beforehand for effective coverage without losing excessive amounts of flying time to refuel. In some areas (e.g. Arabian Peninsula) the availability of fixed-wing aircraft fuel (Avgas) is very limited and it may be necessary to use helicopters (Jet A1 fuel is more widely available). Sometimes it is possible to get support from military aircraft for surveys.

9.2.5 Transect Aerial Surveys

Introduction

A suitable aircraft is flown along predetermined parallel flight lines (transects) and the location of sightings is recorded. With strip-transect aerial surveys the aircraft usually has a frame or other device on the outside of the aircraft to demarcate the predetermined width of the search area. Only sightings within this area are included. A high level of rigour is required in the flying of the aircraft (maintaining exact altitude and flight line) and in the recording of the sightings if repeat surveys are to be compared. The method is most suited to surveys of large areas, where the water is relatively clear. It is generally limited to near-shore waters (up to about 60 km from shore) due to refuelling logistics.

Information that can be obtained

This is a reliable method of estimating the abundance and distribution of many species over large areas. With appropriate correction factors it is possible to derive estimates of absolute abundance. The use of different habitats and the extent of preferred habitat can be determined. The same surveys can be repeated at intervals of several years to monitor changes in the size of populations (e.g. PREEN in press). The same surveys can also be repeated at much shorter intervals to

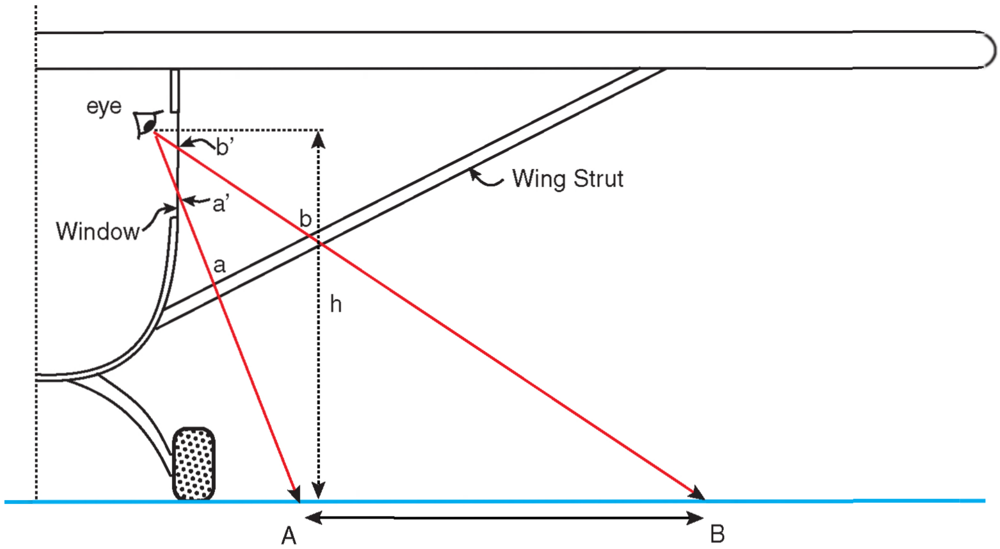

Figure 9.1 Calibrating transect markers

1. Prop the aircraft into the flying attitude.
2. Sit first observer in their seat and get them to 'sag' into a comfortable and realistic position for observing.
3. Measure the height h, that is, the height of the observer's eye above the floor.
4. Fix the position of the inner transect marker (a) so that it is close to the aircraft body, without being obstructed by the bottom of the window.
5. Put a mark, A, on the ground, and a mark a' on the window such that the observer's line of sight passes from a' through a to A.
6. Place a second marker on the ground at B. The distance between A and B is derived from the formula:
   w = W . h/H where:
   W = the required transect width (e.g. 200 m or 215 m)
   H = the flying height
7. While the observer maintains the a' – A line of sight, he puts a second mark on the window at b'.
8. The outer transect marker is adjusted to position b, such that the observer has a straight line of sight b' through b to B.
9. Repeat for the observer on the other side of the aircraft.

If two observers are used on each side of the aircraft then the position of the transect markers is defined by the mid-seat observers. The rear-seat observers must mark their windows with *a'* and *b'* marks so that they are observing the same transect as the mid-seat observers. They may need to use cushions to adjust their head height.

If the observers always keep their heads in the correct observation position then the transect width defined by the lines *a'–a* and *b'–b* will define the correct transect width, when flying at the correct altitude (Figures 9.1 and 9.2).

determine the seasonal distribution of species, which is important information for management planning. Such information may also provide insights into movement patterns and ecological links with neighbouring countries. Transect aerial surveys can also provide very valuable data on the distribution, habitat use and abundance of marine turtles and seabirds, as well as data on fishing and other vessels, nets and fish traps, and oil pollution incidents.

Expertise needed

A crew of at least two observers, plus a flight controller is required as well as the pilot. The observers need to be experienced at identifying marine mammals from the air and must not be prone to motion-sickness. The design and analysis of transect aerial surveys requires the controller to have a sound understanding of strip- and line-transect methodology and good statistical, computer and cartographic skills.

Equipment needed

High-wing aircraft with a very low stalling speed or helicopters are suitable for this work. Helicopters are usually much more expensive to charter (unless military assistance is available) and tend to have lower endurance. For safety reasons a twin-engined aeroplane is desirable if the transects extend far out to sea. Ideally the aircraft will have a GPS and a radar altimeter. Observers require polarized sunglasses. The controller requires binoculars, maps, data sheets or computer. An intercom for communication between the observers and the controller is virtually essential. A computer is necessary for data analysis. A tape recorder is useful for documenting observations and is essential if a larger team of observers is used.

Costs

This type of survey is expensive to conduct due to the large number of flying hours involved. Ancillary equipment can be expensive, but once purchased or assembled is available for subsequent surveys. The salaries of the observers and the time-consuming analyses must also be accounted for.

Method

Strip-transects are a special type of line-transect where it is assumed that all animals visible within the width of the transect are seen. To ensure that this occurs, the transect width is very narrow. On dugong surveys it is usually 200 m on each side of the aircraft.

The advantage of the strip-transect survey is that it is not necessary to measure the distance and angle to each sighting, as required for line transects. This is important in near-shore environments where many animals (dugongs, turtles, dolphins, seabirds) and human activities (fishing boats etc.) may be seen in close proximity[1].

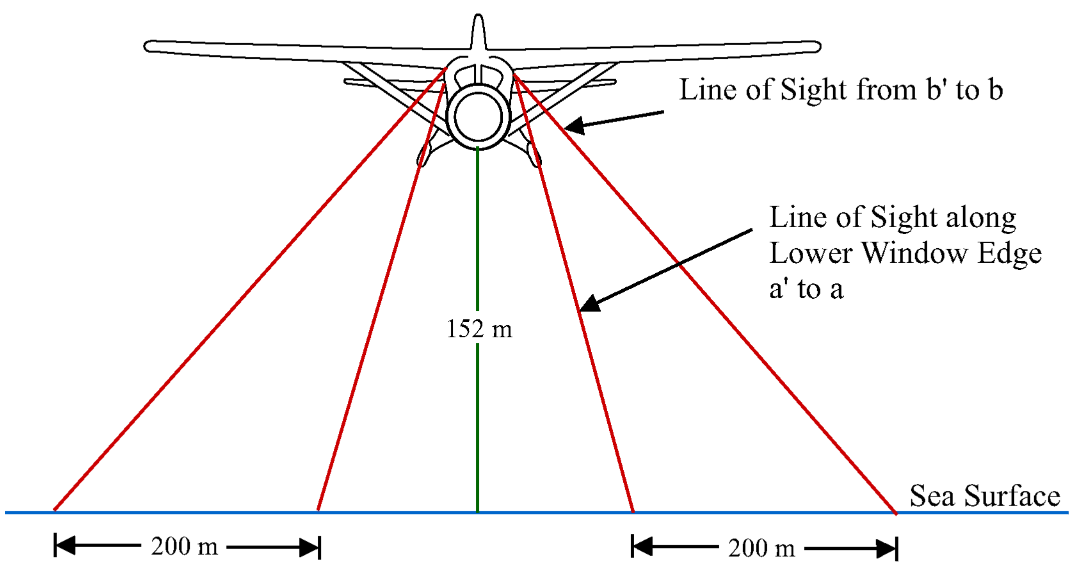

Figure 9.2 Plane flying with transect widths of 200 m

[1] Line–transect surveys are more frequently used for open ocean surveys of cetaceans, where the sighting rate is much lower. If open–ocean species of cetacean are the taxa of interest then it is necessary to modify the line transect boat surveys, described above, for aircraft.

Strip-transect aerial surveys are typically designed to cover large areas (5,000–50,000 km^2). Transect density will be determined, in part, by the amount of suitable habitat in the survey area: transects should be denser in areas where animals are more likely to be encountered. For the estimation of regional densities, the survey area is usually stratified into blocks, and these may have different transect densities. Typically transects are about 9–10 km apart in areas of probable low density (such as offshore areas) and 3–4 km apart in areas of better habitat. Tighter transects may be flown in smaller areas where the major aim is to produce a detailed plot of distribution.

Flight efficiency (or cost) usually dictates that transects are arranged parallel to each other. Therefore, at least the position of the starting transect should be selected randomly. Ideally, transects should run perpendicular to the depth contours.

Transect markers may take the form of a frame or fixed rods attached to the wing struts and wheel supports of the aircraft (see Figure 9.1). A simpler method involves using a thin rope trailing from the wing struts. A funnel attached to the free end of the rope ensures that the rope flies straight and horizontal. Attaching transect markers to helicopters is more difficult due to the safety issues related to detached markers getting caught in the rotor blades. Approval for any external attachments may have to be obtained from the aviation authorities. Figure 9.1 shows how to adjust the transect markers to achieve the desired transect width.

The aircraft flies at an altitude of 500 ft (152 m) and a speed of 90–100 kn (167–185 km/h) while on the transect.

Any change in flying height affects the effective transect width and, hence, the sampling intensity (Figure 9.2). The altitude of the aircraft must be kept constant during surveys and, if using a barometric altimeter, deviations as a result of air pressure changes during the flight must be measured. This is done by recording the difference between the actual elevation of the airstrip where the aircraft lands with the altitude of the strip measured with the barometric altimeter.

The 'sightability' (the ability to spot and identify) of smaller marine mammals and turtles declines as survey conditions deteriorate. If surveys are to be repeated to monitor populations over time, it is essential that survey conditions are kept as similar as possible for each survey. Surveys should be conducted in the season of lowest winds (based on meteorological data where possible, or on the knowledge of experienced fishermen). During surveys, flying should only be conducted when the wind is less than about 15 kn (28 km/h; Beaufort sea state ≤3). To reduce the effects of reflected glare, surveying should not be conducted during early mornings or late afternoons. Unless the sea is very calm, glare is usually unacceptable during the middle of the day as well. Observers should wear polarized sunglasses to reduce the effects of glare.

The survey team will consist of a controller and either two or four observers, depending on the configuration of the aircraft. Four observers are desirable, as more precise perception bias correction factors can be derived.

If only two observers are used (one on each side) the controller must act as a part-time observer and periodically rotate the sides of the observers. When four observers are used, two search the same area on each side of the aircraft. The two observers on each side must be visually and acoustically isolated from each other so their observations are independent (one cannot take a cue from the comments or behaviour of the other). Curtains are used for visual separation while the intercom ensures acoustic isolation.

A four-observer team requires an aircraft with six seats that provide clear views of the search area. The pilot and controller sit in the front seats, with two observers (port and starboard) in each of the mid and rear seats. While on transect the mid-seat observers can talk to one another and to the controller, while the rear-seat observers can only communicate with each other. Between transects and during transit the intercom is opened up for free communication. All communications are recorded by a stereo tape recorder for later transcription. These tapes make it possible to determine the degree of agreement between paired observers so the perception bias correction factors can be derived. During the survey the controller records the sightings of the mid-seat observers onto a computer or onto data sheets. These data act as a backup in case of tape failure. Appendix 9.6.8 provides data sheets for strip transect aerial surveys.

The following information is recorded for each observation: time, transect, direction the transect is flown, observer, number in group, number at surface, number of calves, position in transect, species and confidence of species identification. Position in transect (high, middle, low) is used to distinguish between simultaneous sightings made by observers on the same side of the aircraft. The start and end times of each transect are also recorded and the location of each sighting is based on elapsed time and the known length of each transect. Information on sighting conditions (Beaufort sea state and level of glare on each side of the aircraft) and flying height is recorded every few minutes. If a barometric altimeter is used to maintain survey height then the altimeter height of the airstrip is recorded at each take off and landing. This information, with the actual airstrip altitude, is used to correct the altimeter measurements of flying height for each transect.

For aerial surveys to be used to estimate abundance and to monitor trends in abundance through time, it is necessary to correct for the number of animals not seen by observers. Following MARSH & SINCLAIR (1989) corrections are needed for two types of bias:

1. ***Perception bias***: those animals that are visible within the transect, but are missed by the observers. Correction factors are calculated by using paired but independent observers, one behind the other. The numbers of animals seen or missed by each observer are used in a mark-recapture analysis to estimate the proportion of animals missed by either or both observers.
2. ***Availability bias***: those animals that are below the surface and are not visible. A correction factor for this bias is estimated by
   a) recording during the survey which animals are at the surface and
   b) studying individuals of the same species to determine what proportion of time they spend at the surface.

   The extent to which surface time varies between place, time, water depth and behaviour is not known, but is likely to reduce the accuracy of availability bias correction factors. However, as better data become available, correction factors can be adjusted and previous surveys re-analysed.

9.3 DATA ANALYSIS

After the survey the tape records of each transect are used to edit the controller's record of the sightings of the mid-seat observers. Each sighting is identified as made by the mid-seat, rear, or both observers on the relevant side. The perception bias correction factors for each pair of observers and its coefficient of variation are estimated using the following formulae (MARSH & SINCLAIR 1989):

$$PCF = [(S_m + b)(S_r + b)] / [b(S_m + S_r + b)]$$

and

$$CV = [(S_m + S_r) / (S_m + S_r + b)] * \{(S_m * S_r) / [b(S_m + b)(S_r + b)]\}$$

where:

PCF = perception bias correction factor

CV = coefficient of variation of the correction factor

S_m = number of groups seen by the mid-seat observer only

S_r = number of groups seen by the rear-seat observer only

b = number of groups seen by both observers

The availability bias correction factor and its coefficient of variation can be estimated from the formulae:

$$ACF = p_u / p_s$$

and

$$CV = \{[(1-p_u) / (p_u N_u)] + [(1-p_s) / (p_s N_s)]\}$$

where:

ACF = availability correction factor

CV = coefficient of variation of the estimate of the ACF

p_s = the proportion of animals seen at the surface during an aerial survey of clear-water habitat where all animals could be seen

p_u = the proportion of animals seen at the surface during the aerial survey being analysed

N_u = the total number of animals (e.g. dugongs) seen during the aerial survey

N_s = number of animals (e.g. dugongs) seen during a survey of clear water habitat

An estimate of p_s may be derived by other methods, including multiple records of surfacing and diving intervals of a large number of individuals or the use of time-depth recorders. Differences in habitat, water depth or behaviour may mean that the proportion of animals at the surface may not be the same for the two sets of data used to derive p_s and p_u. However, the ratio of p_u/p_s provides a useful means of standardizing fluctuating availability bias for repeat surveys of the same area. The ratio 80:480 has been used as an estimate of p_s for dugongs in shallow water (<10 m) in Australia.

There are no commonly available computer programmes for the analysis of strip-transect aerial surveys, so the main steps involved in the analysis are provided here. These procedures, to convert aerial survey data (counts of groups of target species) to population estimates are largely taken from MARSH & SINCLAIR (1989):

1. Use the actual flying height of each transect to determine the actual width of the search area.

2. Determine whether each group seen on each side of the aircraft was seen by the mid-seat, rear-seat or both observers.

3. Calculate the mean group size (and standard error) for the whole survey.

4. Calculate the perception bias correction factor (and CV) for each side of the aircraft.

5. Calculate the availability bias correction factor (and CV) for the survey.

6. Determine the corrected number of animals for each transect by multiplying the number of groups seen by the port and starboard survey teams on each transect by:

    a) the appropriate perception bias correction factor,

    b) the availability correction factor, and

    c) the mean group size

    and then sum the corrected values for the port and starboard sides for each transect.

7. Assuming not all transects are the same length, use the ratio method (JOLLY 1969) and the corrected number of sightings for each transect to estimate the size of the population and its variance using the following formulae:

$$Y = A*R$$

and

$$S^2 = [T(T - t) / t] * (S_y^2 - 2RSay + R^2S_a^2)$$

where:

Y = estimated size of the population in the survey block

A = area of the survey block

R = ratio of the corrected number of animals counted to the area searched

$= \Sigma y / \Sigma a$

a = area of any one transect

y = total corrected number of animals counted in that transect

S^2 = sampling variance of Y

T = total number of transects that could fit into the survey block

t = number of transects sampled

S_y^2 = variance between the corrected number of transects counted on all transects

$= [1 / (t - 1)] * (\Sigma y^2 - \{[(\Sigma y)^2] / t\})$

S_a^2 = variance between the areas of all the transects

$= [1 / (t - 1)]*(\Sigma a^2 - \{[(\Sigma a)^2] / t\})$

S_{ay} = covariance between the corrected number of animals counted on a transect and the area of the transect

$= [1 / (t - 1)]*(\Sigma ay - \{[(\Sigma a)(\Sigma y)] / t\})$

8. Calculate the variance of the total population estimate using the following formula:

$$\text{var} = S^2 + Y_p^2(C_g^2 + C_{pp}^2 + C_a^2) + Y_s^2(C_g^2 + C_{sp}^2 + C_a^2)$$

where:

S^2 = sampling variance of Y in step 6

Y_p = contribution to the corrected population estimate made by the port observation team

Y_s = contribution to the corrected population estimate made by the starboard observation team

C_g = coefficient of variation of the mean group size

C_{pp} = coefficient of variation of the perception bias correction factor for the port team

C_{sp} = coefficient of variation of the perception bias correction factor for the starboard team

C_a = coefficient of variation of the availability bias correction factor

Equivalent calculations are done to estimate the population density and its variance. These formulae can be modified if only two observers are used (see PREEN 1989).

9.4 A PHASED APPROACH TO MARINE MAMMAL SURVEYS

The skills, infrastructure and budgets required to conduct marine mammal surveys properly range from low to high, depending on the methods employed (Table 9.2). Where resources are strictly limited, there is a strong case for a phased approach to marine mammal survey work: start with the simplest and work up to the more complicated and more expensive methods. A research programme should start with those approaches that can yield valuable information for least commitment of resources. Interview surveys and a carcass salvage programme could, for very little expense, greatly increase the information known about the marine mammals of most Red Sea and Gulf of Aden countries. These programmes may be supplemented by some shoreline aerial surveys to confirm some of the information provided by informants and to give the researchers a good overview of the marine habitats of the region.

Armed with the information from these surveys it should be possible to design good boat or transect aerial surveys. These surveys require some information on the distribution and abundance of marine mammals and habitats for the optimal location and density of transects. One of the great values of these surveys is that they can be repeated so populations can be monitored over time. However, subsequent surveys should exactly duplicate the first survey. Hence, it is most important that the initial survey is well-designed and the more information that is available the better this can be done.

When designing any marine mammal survey it is worth remembering the mobility of these species. Where possible, joint surveys between neighbouring countries are desirable as it is very likely that the mammals being surveyed cross the territorial boundaries between countries.

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Appendix 9.6.1 Information sought from fishermen about the status of dugongs in Saudi Arabia and Yemen (PREEN 1989).

The questions were posed during extended conversations.

What is your name?

How old are you?

How long have you lived/fished in this area?

What is the range of the area in which you fish?

Do you know the dugong?

Can you describe it?

Do you recognise it in any of these photos? (series of photos of marine animals)

What do they feed on?

Do you see them often? How often?

Do you think dugongs are more common, less common, or about the same as 10 years ago, 20 years ago, 30 years ago?

Do they get caught in your fishing nets?

What season do you see/catch the most?

In which area do you see/catch the most?

What happens to dugongs caught in your nets? Do you release them or kill them or do they accidentally drown?

Do you eat them? Do you use any other parts of the animal? What for?

Do you hunt dugongs or did you in the past? If so, how do/did you catch them?

How many do you catch (accidentally or deliberately) in a year?

When was the last time you caught one?

Do other fishermen in this area catch them?

How many would get caught by the whole village in a year?

When was the last one caught?

Do you sell any dugongs?

If so, where do you sell them and how much do you get per kilogram/for the whole animal?

Appendix 9.6.2 Example of a sighting sheet used to gather information from the public about marine mammal distribution in a particular area (Preen 2000).

Observers were asked to mark the location of their sighting and the path of their boat on a map, to answer the questions about the sighting, and to post the sheet to the researchers. The illustrations were provided to help people identify the marine mammals they saw.

CETACEAN SIGHTING RECORD

Please circle the appropriate options

SPECIES: Dugong / False Killer whale / Killer whale / Bottlenose dolphin / Humpback dolphin / Common dolphin / Risso's dolphin / Pantropical spotted dolphin / Striped dolphin / Spinner dolphin / Rough-toothed dolphin

CONFIDENCE OF IDENTIFICATION: Certain / Probable / Guess

Date: _______________

SEEN FROM: Shore / Sailing Boat / Powerboat at anchor / Powerboat travelling

NUMBER IN GROUP: ____ NUMBER OF CALVES: _____ PHOTOS: Yes / No

(include a copy if possible)

LOCATION (GPS): ____

WEATHER (wind, waves, clouds, etc): ____

COMMENTS (activity etc): ____

____

NAME OF OBSERVER: ______________________PHONE: ___________________

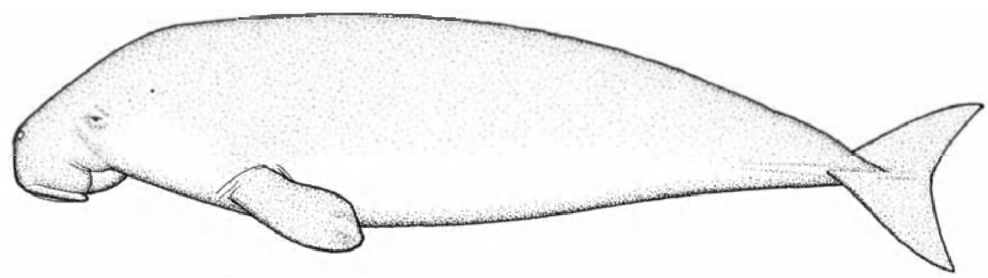
CONTACT ADDRESS: ____

SEND RECORDS TO:

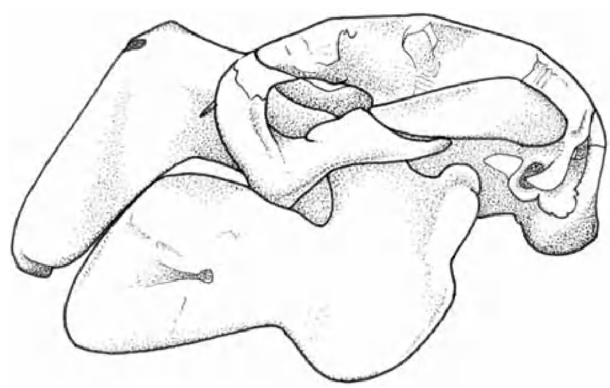
PERSGA, P.O. Box 53662, Jeddah 21583, Kingdom of Saudi Arabia

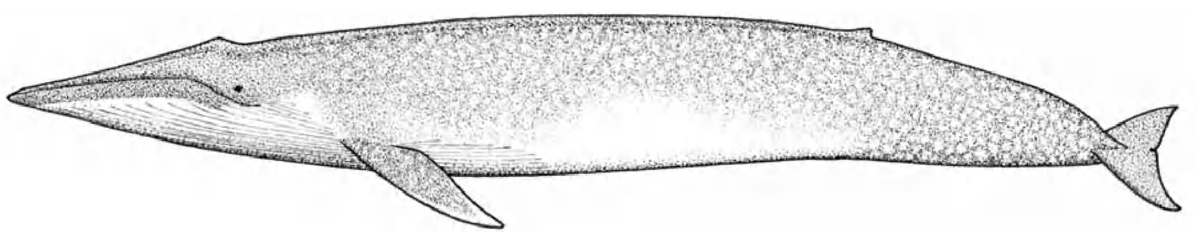
Fax: +966 2 652 1901

Appendix 9.6.3 Marine mammal guide to identification.

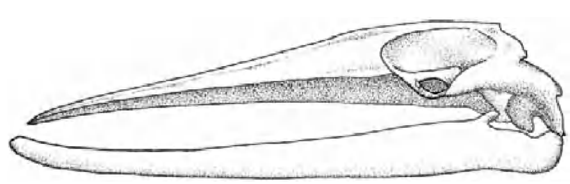


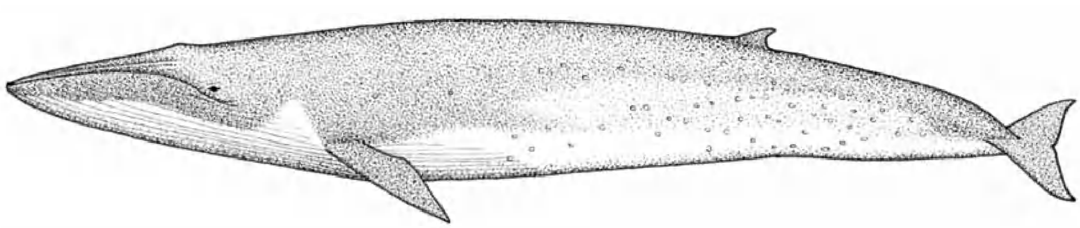
Dugong
Dugong dugon



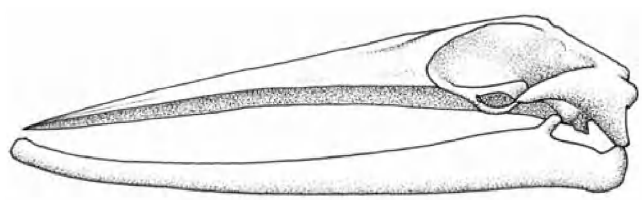


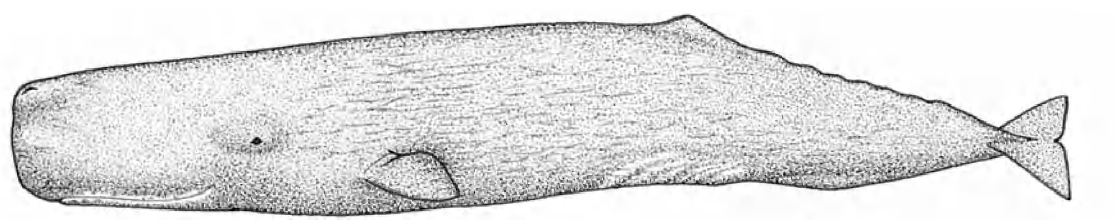
Blue whale
Balaenoptera musculus



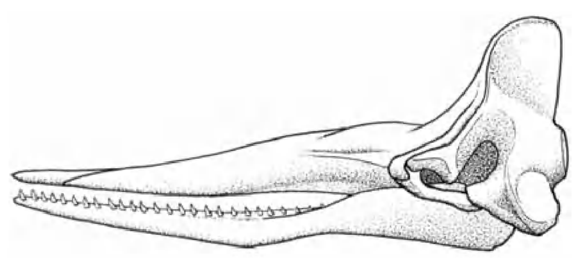


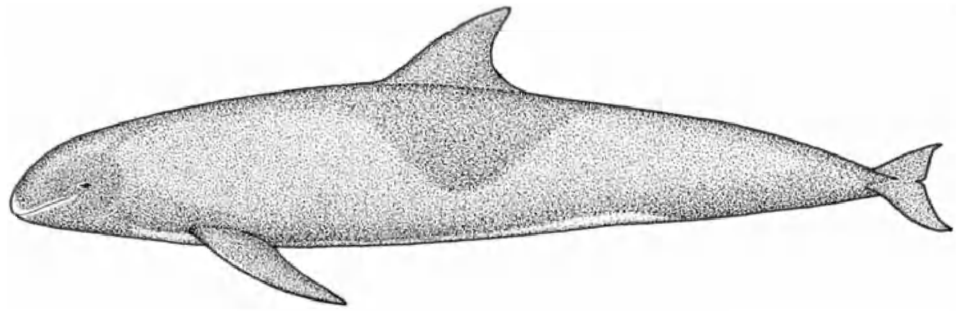
Bryde's whale
Balaenoptera edeni



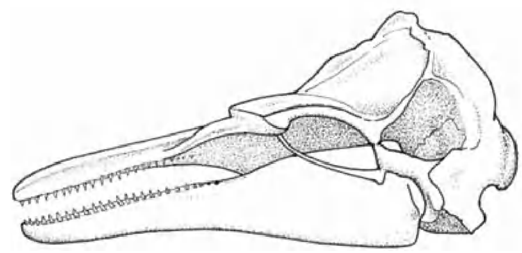


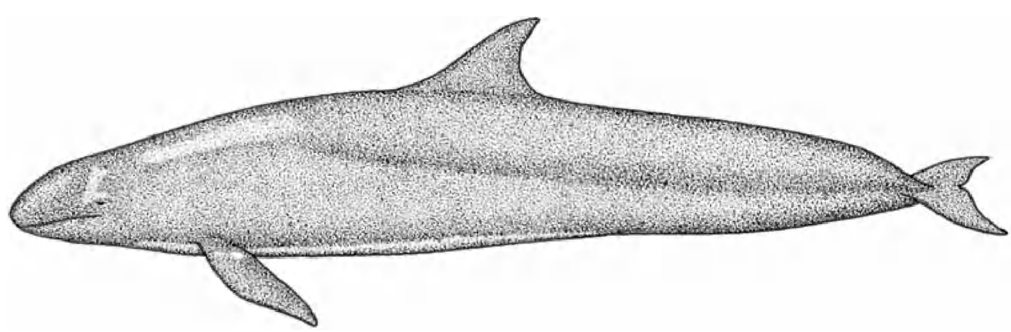
Sperm whale
Physeter macrocephalus



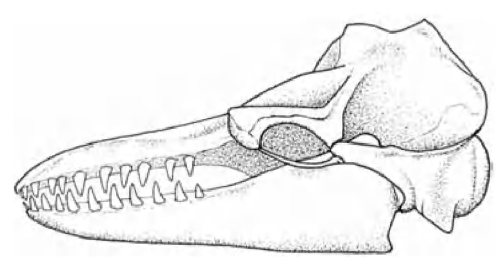


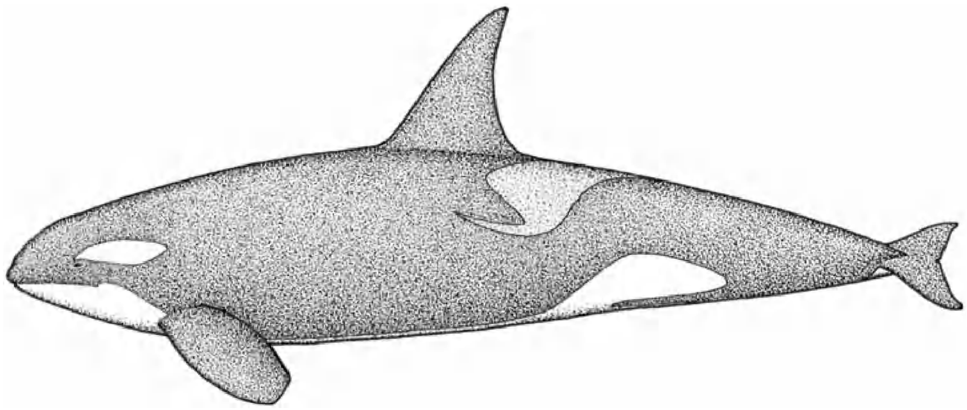
Melon–headed whale
Peponocephala electra



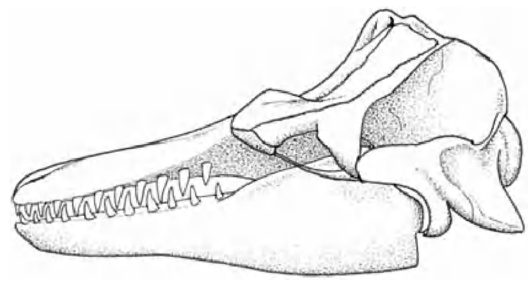


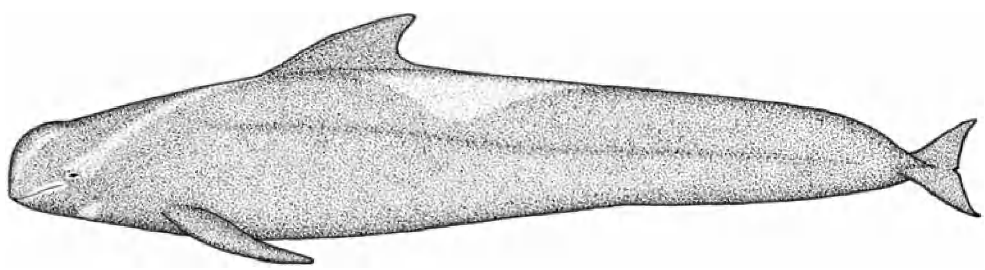
False killer whale
Pseudorca crassidens



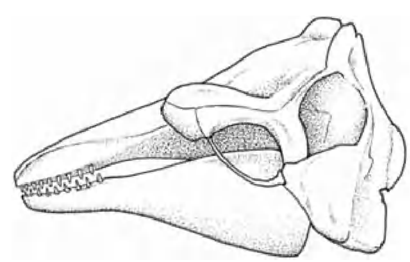


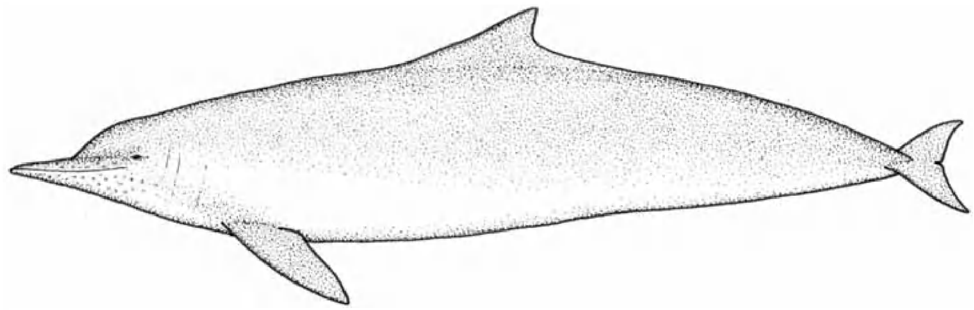
Killer whale
Orcinus orca



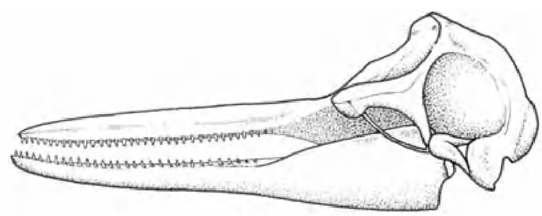


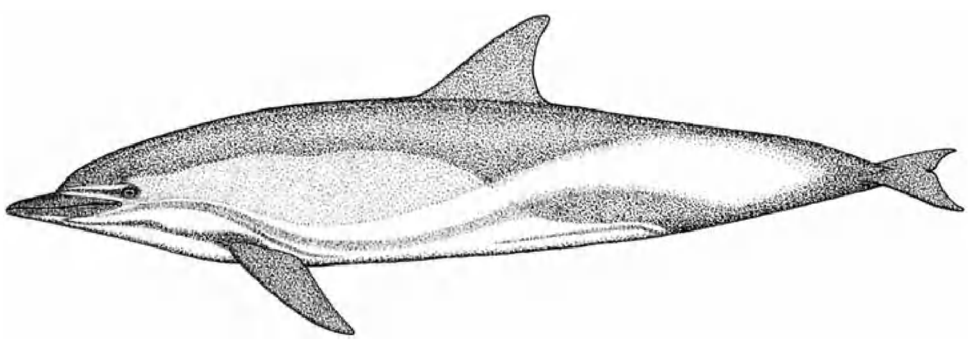
Short–finned pilot whale
Globicephala macrorhynchus



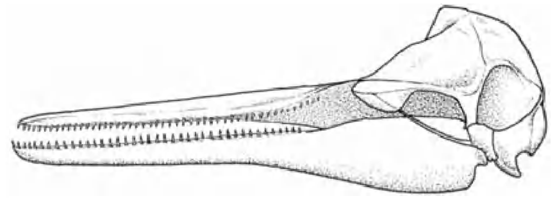


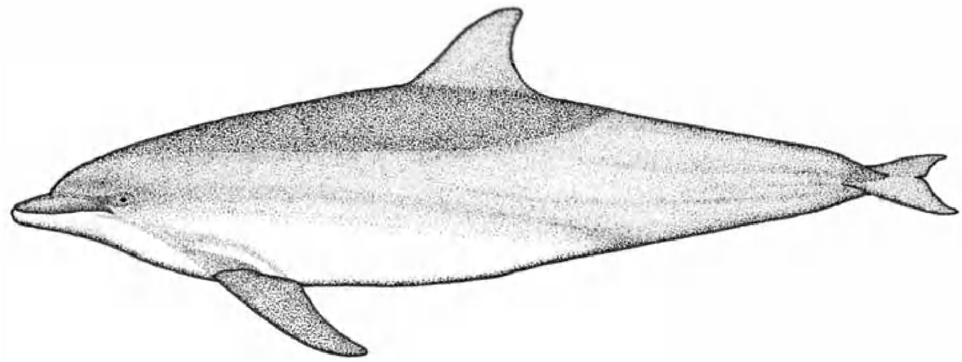
Indo–Pacific humpbacked dolphin
Sousa chinensis



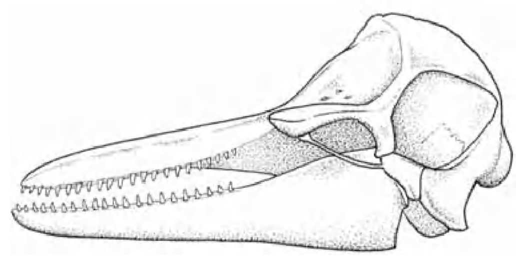


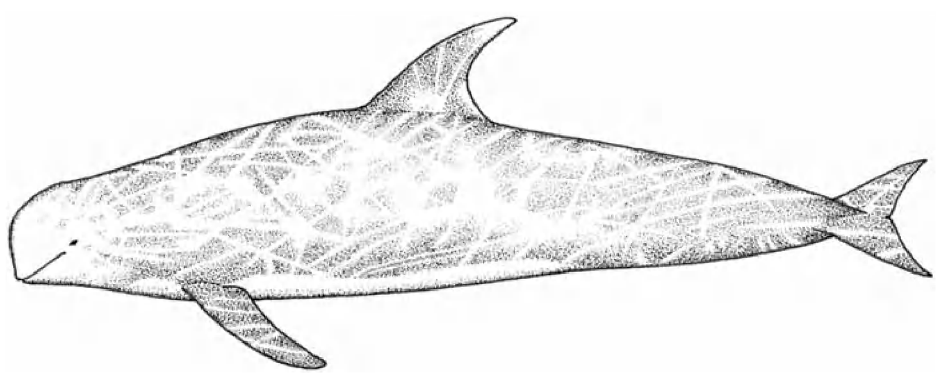
Common dolphin
Delphinus delphis



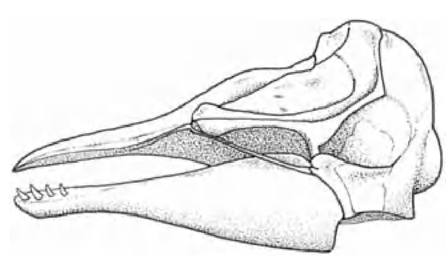


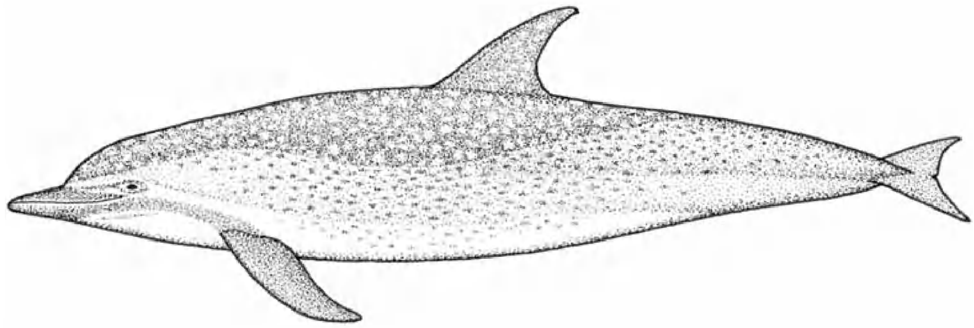
Bottlenose dolphin
Tursiops truncatus



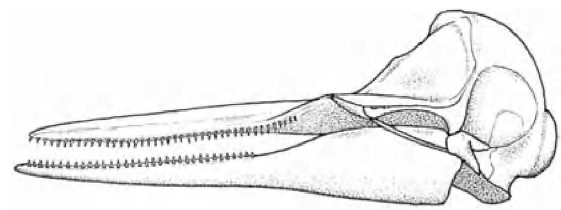


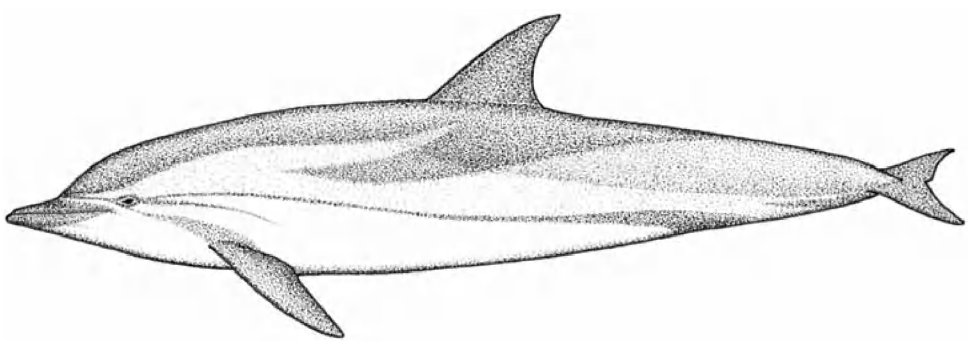
Risso's dolphin
Grampus griseus



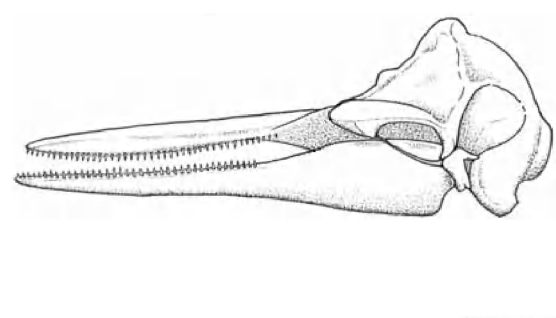


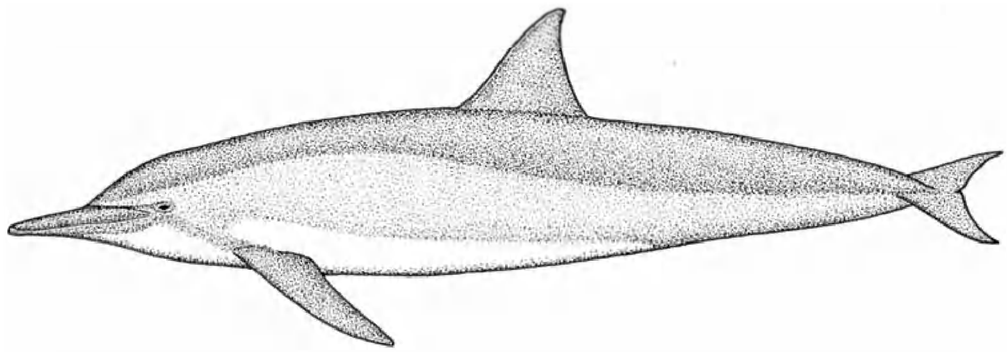
Pantropical spotted dolphin
Stenella attenuata



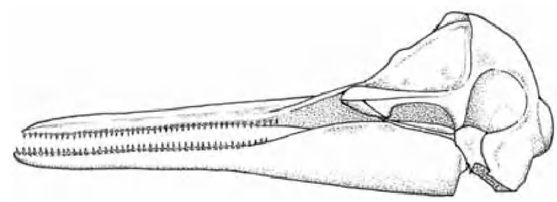


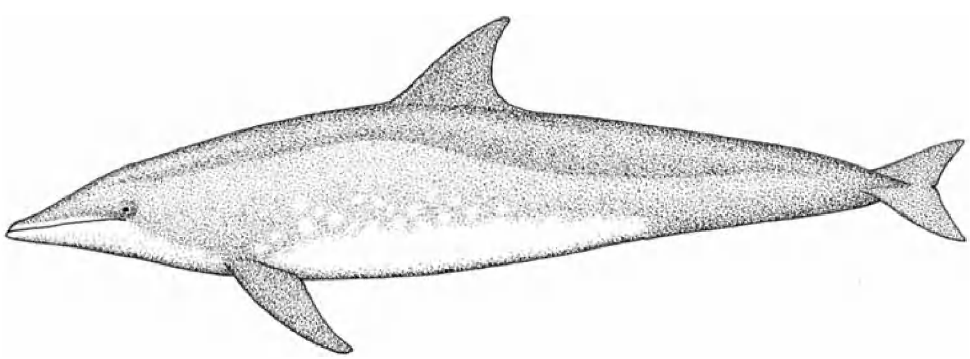
Striped dolphin
Stenella coeruleoalba



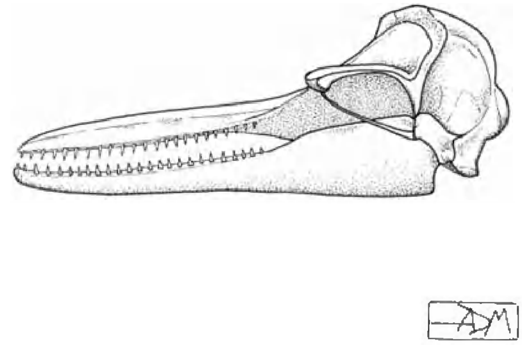


Spinner dolphin
Stenella longirostris





Rough–toothed dolphin
Steno bredanensis



Appendix 9.6.4

SIMPLE IDENTIFICATION GUIDE AND CARCASS DATA SHEET (PREEN et al. 1989)

Information on the species, sex and size of these animals can provide useful information on the structure, dynamics and health of the Red Sea marine mammal populations. Once a baseline of data is collected, so that it is known at what rate animals normally die along the coast, the incidence of stranding may prove a useful indicator of major pollution or disease events and therefore an indicator of the health of the Red Sea generally.

Marine mammals can be identified by the following characteristics:

- They have one or two blow-holes (nostrils) on top of their head through which they breathe.
- They have smooth skin (dugongs have very sparse fine hairs).
- Their tail is flattened horizontally and it moves with an up-and-down motion. The tails of fish are flattened vertically and move from side to side.
- A description of four common marine mammal species occurring in the Red Sea and the Gulf of Aden is given on the following page.

How to Measure Size and Determine Gender

The Figure 9.3 overleaf illustrates how to determine the sex and measure the length of a marine mammal. Body length is the straight line distance (not curved) between the tip of the snout and the notch of the tail fluke.

The sex of the marine mammal is determined by inspecting the relative distance between anus, genital slit and navel scar on the belly of the animal. In females the genital slit is very close to the anus, while in males the genital slit is more equidistant between the navel and the anus.

Data Sheet – Marine Mammal Carcass

A data sheet is given so that all observers may record their data in a standard format. The data requested is the minimum necessary for the information to be useful.

Photographs

It is very helpful if photographs are taken of each dead animal. These photographs may provide the specialist with information which could not be collected by the beach surveyor.

Dugongs

Dugong skulls are of particular scientific value and should be collected from carcasses whenever possible.

Send data sheets, photos and skulls to:

PERSGA, P.O. Box 53662, Jeddah 21583, Kingdom of Saudi Arabia

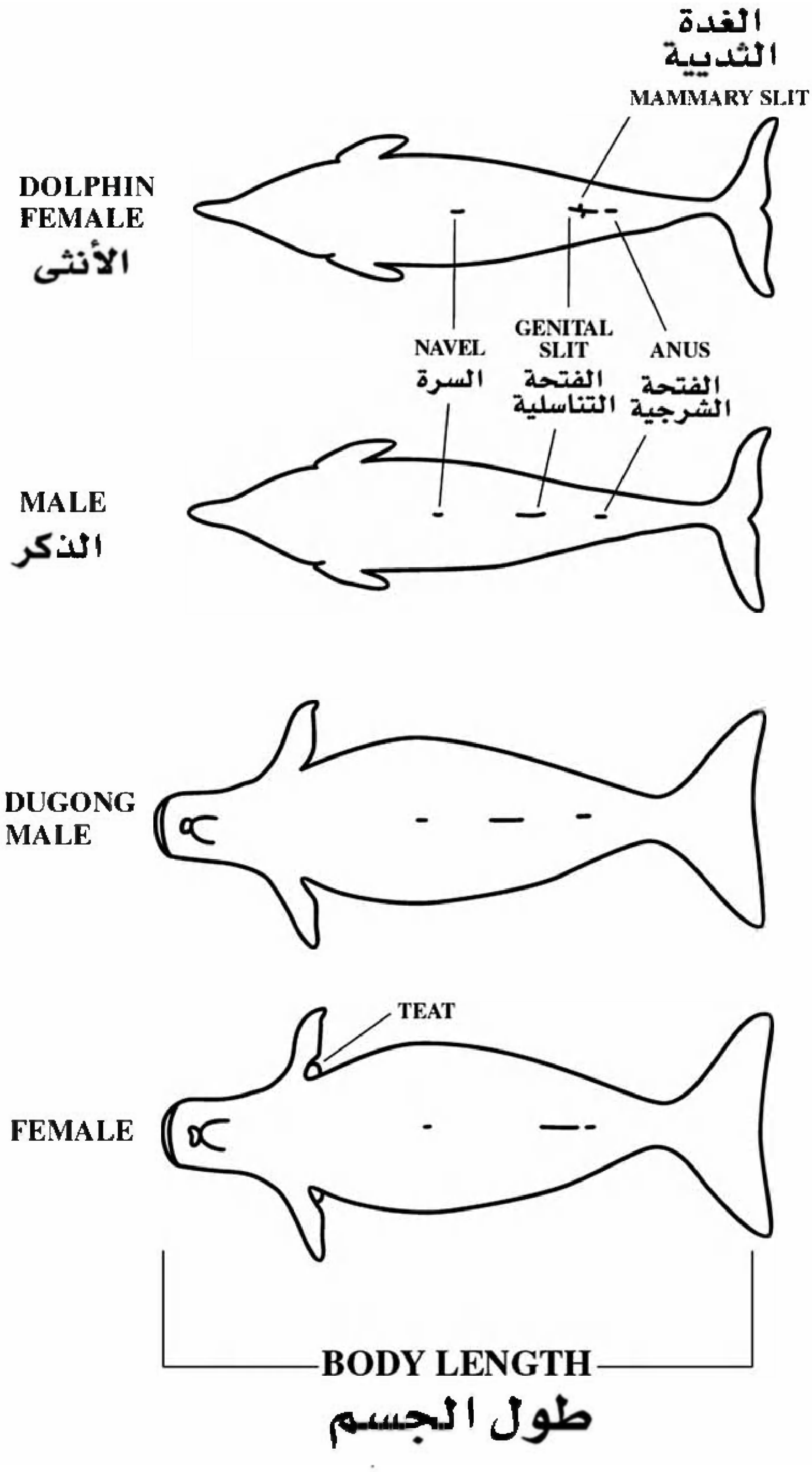
DESCRIPTION OF FOUR COMMON MARINE MAMMAL SPECIES FROM THE RED SEA AND GULF OF ADEN

Species:	**Dugong**
Scientific Name:	*Dugong dugon*
Body Length:	Up to 3 m
Dorsal fin:	No dorsal fin
Snout:	Blunt, enlarged, with coarse bristles on lower surface
Teeth:	2 to 5 large flattened teeth in the back of each jaw. In sexually mature males, large incisors occur at the tip of the upper snout.
Colour:	
Live:	Light brown to grey
Dead:	Dark brown to grey
Tail:	Large, without pronounced notch (which is characteristics of dolphins)
Teats:	1 to 4 cm long, just behind flippers.

Species:	**Bottlenose dolphin**
Scientific Name:	*Tursiops truncatus*
Body Length:	Up to 3.5 m
Dorsal fin:	High, curved backwards
Snout:	Short and stout
Teeth:	20 to 29 in each side of each jaw
Colour:	
Live:	Grey back, light belly
Dead:	Black

Species:	**Common dolphin**
Scientific Name:	*Delphinus delphis*
Body Length:	Up to 2.5 m
Dorsal Fin:	Very high, curved backwards
Snout:	Long and slender
Teeth:	45 to 57 in each side of each jaw
Colour:	
Live:	Dark grey above, pale below, crisscross pattern of tan and grey on flanks
Dead:	Black

Species:	**Humpback dolphin**
Scientific Name:	*Sousa chinensis*
Body Length:	Up to 3 m
Dorsal Fin:	Relatively small, curved backwards with rounded tip. Often set on an elongated hump in the middle of the back.
Snout:	Long
Colour:	
Live:	Light to dark grey, sometimes speckled with darker spots
Dead:	Black



يوضح طريقة قياس طول الجسم وتحديد الجنس للثديات البحرية

Figure 9.3 How to measure dolphin and dugong length and to determine sex

DATA SHEET – STRANDED MARINE MAMMAL CARCASS

بطاقة تسجيل بيانات
للثديات البحرية المُعَرّفة

Date: ____ **: التاريخ**

Name of Recorder: ____________________________________ **: اسم المسجل**

Location of Carcass: ______________________ : (تحديد المسافة والاتجاه) **موقع وجود الحيوان الميت**

____

(Lat./Long.)____

Species: ____ **: النوع**

Sex: Male / Female / Could not tell **الجنس :** ذكر / أنثى / غير معروف

Body Length: _____ Metres ______________ **: طول الجسم**

Photos Taken: Yes/No? **هل تم التصوير :** نعم / لا

Skull Collected: Yes/No? **هل جمعت الجمجمة :** نعم / لا

Where is the skull now?________________________________ **: أين الجمجمة الآن**

____

Comments:____ **: ملاحظات**

____

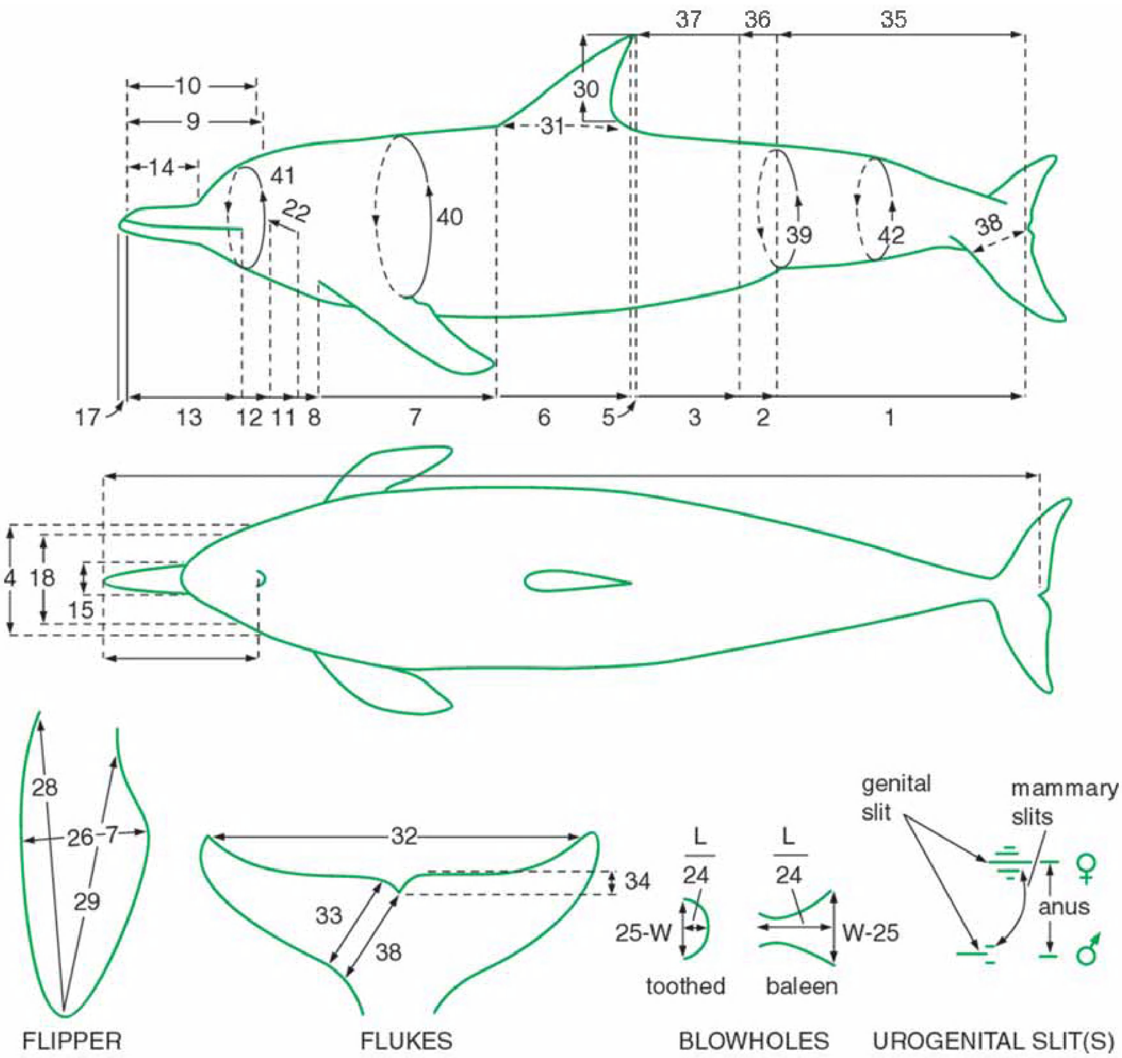
Address and Telephone Number of Recorder: ________________ **: عنوان المسجل**

____

Please send data sheets, photos and skulls to:

PERSGA, P.O. Box 53662, Jeddah 21583, Kingdom of Saudi Arabia

Appendix 9.6.5 Cetacean data record schematic.



Locations and details of important measurements

Figure 9.4 Schematic for collecting morphometric data from cetaceans (Leatherwood et al. 1976)

CETACEAN DATA RECORD

SPECIES________________________SEX_______LENGTH________WEIGHT__________
DATE/TIME STRANDED___________________ DATE/TIME COLLECED ____________
LOCATION OF COLLECTION ____
OBSERVER NAME / ADDRESS ____
SPECIMEN SENT TO ____

MEASUREMENTS:

No.	Measurement	**Straight line parallel to the body axis**	**Point to Point**
1.	Tip of upper jaw to deepest part of fluke notch	____________	____________
2.	Tip of upper jaw to centre of anus	____________	____________
3.	Tip of upper jaw to centre of genital slit	____________	____________
4.	Tip of lower jaw to end of ventral grooves		____________
5.	Tip of upper jaw to centre umbilicus	____________	____________
6.	Tip of upper jaw to top of dorsal fin	____________	____________
7.	Tip of upper jaw to leading edge of dorsal fin	____________	
8a.	Tip of upper jaw to anterior insertion of flipper (right)	_ ____________	____________
b.	Tip of upper jaw to centre of blowhole(s)	____________	____________
10.	Tip of upper jaw to anterior edge of blowhole(s)	____________	____________
11a.	Tip of upper jaw to centre of eye (right)	____________	____________
b.	Tip of upper jaw to centre of eye (left)	____________	____________
12a.	Tip of upper jaw to centre of eye (right)	____________	____________
b.	Tip of upper jaw to centre of eye (left)	____________	____________
13.	Tip of upper jaw to angle of gape		____________
14.	Tip of upper jaw to apex of melon	____________	
15.	Rostrum – maximum width	____________	____________
16.	Throat grooves – length	____________	____________
17.	Projection of lower jaw beyond upper (if reverse, so state)	___________	
18.	Centre of eye to centre of eye		____________
19a.	Height of eye (right)	____________	
b.	Height of eye (left)	____________	
20a.	Length of eye (right)	____________	
b.	Length of eye (left)	____________	
21a.	Centre of eye to angle of gape (right)	____________	____________
b.	Centre of eye to angle of gape (left)	____________	____________
22a.	Centre of eye to external auditory meatus (right)	____________	____________
b.	Centre of eye to external auditory meatus (left)	____________	____________

		Straight line parallel to the body axis	**Point to Point**
23a.	Centre of eye to centre of blowhole (right)	______	______
b.	Centre of eye to centre of blowhole (left)	______	______
24.	Blowhole length	______	
25.	Blowhole width	______	
26.	Flipper width (right)		______
27.	Flipper width (left)		______
28a.	Flipper length – tip to anterior insertion (right)	______	
b.	Flipper length – tip to anterior insertion (left)	______	
29a.	Flipper length – tip to axilla (right)	______	
b.	Flipper length – tip to axilla (left)	______	
30.	Dorsal fin height	______	
31.	Dorsal fin base	______	
32.	Fluke span	______	
33.	Fluke width	______	
34.	Fluke depth of notch	______	
35.	Notch of flukes to centre of anus	______	______
36.	Notch of flukes to centre of genital aperture	______	
37.	Notch of flukes to umbilicus	______	
38.	Notch of flukes to nearest point on leading edge of flukes	______	
39.	Girth at anus		______
40.	Girth at axilla		______
41.	Girth at eye		______
42.	Girth ____cm in front of notch of flukes		______
43a.	Blubber thickness (mid dorsal)		______
b.	Blubber thickness (lateral)		______
c.	Blubber thickness (mid ventral)		______
44.	Width of head at post-orbital process of frontals	______	
45.	Tooth count: right upper ______		
	right lower ______		
	left lower ______		
46.	Baleen count: right upper ______		
	left upper ______		
47.	Baleen plates, length longest		______
48.	Baleen plates, no. bristles/cm over 5 cm	______	
49a.	Mammary slit length (right)		______
b.	Mammary slit length (left)		______
50.	Genital slit length	______	
51.	Anal slit length	______	

Appendix 9.6.6

DUGONG CARCASS DATA SHEET

Specimen Number: ________

Examined by: ____

Contact Address:____

Location: ____

Date of examination: __________ Time: ________ Estimated time since death: _____________

Condition: live/ fresh dead / fair / bloated / collapsed Photos taken? Yes / No

External marks (bites, nets, etc.) ____

Body length (see illustration) ______ _____________ m

Length of teats: Left ________cm Right _________ cm

Gender (see illustration): Male / Female

Tusks present: Yes/ No

NOTE: This is hierarchy of observations, proceed as far as you feel competent.

Comments on external features:

Skin____

Eyes____

Nostrils ____

Flippers ____

Tail Fluke ____

General physical condition: good / poor

Foetus present? Length_______ Gender _______ Weight _________

Milk being produced? (cut mammary gland) ______________

Comments on internal organs:

Body-wall fat: firm & white / yellow, jelly-like & watery

Stomach: full / half full / less

Intestines: packed with food / relatively empty

external colour: white / yellow / pink / red / other

Liver: colour ________________

edge profile: rounded/ sharp

Respiratory Tract:

Trachea: internal colour: white / pink/ red / other

Lungs: colour: pink / red / other___________

Texture: soft / firm

Heart: colour of surrounding fat: yellow / white / other

Possible Samples (label fully)

Organ	Preparation	Analyses
Body fat	Freeze	Toxins, Heavy Metals
Blood	Anti–coagulant	Red cell count
	No anti–coagulant	Blood chemistry
Skin	Freeze	Genetics
Stomach content	Freeze/formalin*	Diet, toxic dinoflagellates
Liver	Freeze	Toxins
Gall bladder	Freeze	Toxins
Gonads	Formalin/freeze	Reproductive history
Skull	Freeze/deflesh	Age

* 10% seawater formalin (9 parts seawater to 1 part formalin)

Comments:

____

____

____

Date:..   **Name of Recorder:..............................**

Name of boat:..................................... **Skipper:.................................** **Name of Observer:..............................**

Sighting No.	Time of Sighting 24:00	Bearing & Distance from boat		Species	Diagnostic Features	Method of Observation (eye or 7x, 20x bino.)	Behaviour	Group Size (estimate)	Position of Boat at time of sighting		Environmental Conditions (wind, visibility, wave height, water depth)	Photos	
		deg.	(m)						Lat.	Long.		Roll	Frame

Appendix 9.6.7 Data sheet for recording information from a line-transect boat survey.

Appendix 9.6.8
Data sheets for aerial transect survey.

FLIGHT SUMMARY SHEET

Date:______________ Aircraft:_____________________________

Controller/Recorder:________________ Pilot: _______________________________

Observer Left Front:_________________ Observer Right Front:_________________

Observer Left Rear: _________________ Observer Right Rear: _________________

Location start: _____________________ Location end: _______________________

Engine start:______________ Engine shut-down:_______________ Diff.: __________

Altimeter start:____________ Altimeter end: __________________ Diff.: __________

Survey conditions:____

____

Transects flown (in order): ____

____

Notes:____

____

____

____

TRANSECT DATA SHEET

Date:			Transect #:			Trn start:			Trn end:		
Time	Alt	Beauf	Glare	Obs	Sp. type	Grp size	# at surf	Posn in Trn	# calves	Species	ID cert

Trn. start: exact start times of the transect.
Trn. end: exact end times of the transect.
Time: exact time of sighting/record.
Alt.: aircraft altitude read from altimeter. Ensure several records per transect.
Beauf.: sea state using Beaufort scale. Ensure several records per transect.
Glare: a measure of the proportion of the search area affected by glare from the sun. The following scale is suggested: 0 = no affect of glare, 1 = up to 25% of search area affected by glare, 2 = up to 50% of search area affected, 3 = >50% search area affected by glare. Request a glare reading from observers several times during each transect.
Obs.: observer
Sp. type: type of animal or object. Use a unique code for each category e.g. D = dugong, C = cetacean, T = turtle, S = shark, R = ray, B = birds, W = whale shark, V = vessel, N = net.
Grp. size: number of animals/objects in sighting group within transect.
at surf: number of animals within the group that are breaking the water surface. This information is needed for the Availability correction factor.
Posn. in Trn.: position of sighting within the transect (H = high, M = mid, L = low). Important where there are front and rear-seat observers to determine if near simultaneous sightings are of the same or different animals/objects.
calves: number of calves in the group.
Species: more specific identification of species type. Develop unique codes for the types of cetaceans expected in the area. May also need codes for rays (manta, eagle, sting), seabirds, vessels and nets.
ID cert.: Confidence of species identification; this is particularly important for cetaceans. C= certain, P = probable, G = guess.