INTERTIDAL REEF BIOTOPES

An overview of dynamic and sensitivity characteristics for conservation management of marine SACs

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PREFACE

The 1990s are witnessing a “call to action” for marine biodiversity conservation through wide ranging legislative fora, such as the global Convention on Biodiversity, the European Union’s “Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora” (the Habitats Directive) and more recently in developments to the Oslo and Paris Convention (OSPAR). These landmark legal instruments have in turn provided sufficient scientific rationale, legal mandate and social synergy to rally governments, NGOs, private industry and local communities into a new era of unprecedented conservation action.

Each of these initiatives identifies marine protected areas as having a key role in sustaining marine biodiversity. To manage specific habitats and species effectively there needs to be a relatively clear understanding of their present known distribution, the underpinning biology and ecology and their sensitivity to natural and anthropogenic change. From such a foundation, realistic guidance on management and monitoring can be derived and applied.

The Habitats Directive requires the maintenance and/or restoration of natural habitats and species of European interest at favourable conservation status across their biogeographical range. The designation and management of a network of Special Areas of Conservation (SACs) have a key role to play in this. The specific 'marine' habitats defined in Annex I of the Habitats Directive include:

- Sandbanks which are slightly covered by sea water all the time,
- Estuaries
- Mudflats and sandflats not covered by seawater at low-tide,
- Large shallow inlets and bays
- Lagoons
- Reefs
- Submerged or partly submerged sea caves

These habitats are vast in scope and challenging to quantify in terms of favourable conservation status, so there has been increased attention to 'sub-features' of these habitats which are in effect constituent components and/or key elements of the habitats from a range of biodiversity perspectives.

One initiative now underway to help implement the Habitats Directive is the UK Marine SACs LIFE Project, involving a four year partnership (1996-2001) between English Nature (EN), Scottish Natural Heritage (SNH), the Countryside Council for Wales (CCW), Environment and Heritage Service of the Department of the Environment for Northern Ireland (DOENI), the Joint Nature Conservation Committee (JNCC), and the Scottish Association of Marine Science (SAMS). While the overall project goal is to facilitate the establishment of management schemes for 12 of the candidate SAC sites, a key component of the project assesses the sensitivity characteristics and related conservation requirements of selected sub-features of the Annex I habitats noted above. This understanding will contribute to more effective management of these habitats by guiding the detailed definition of the conservation objectives and monitoring programmes and by identifying those activities that may lead to deterioration or disturbance.

A diverse series of sub-features of the Annex I marine habitats were identified as requiring a scientific review, based on the following criteria:

- key constituent of several candidate SACs;
- important components of Annex I habitats in defining their quality and extent;
- extensive information exists requiring collating and targeting, or there is minimal knowledge needing verification and extended study.

This resulted in the compilation a nine-volume review series, each providing an "Overview of Dynamics and Sensitivity Characteristics for Conservation Management of Marine SACs" for the following sub-features:

Vol. I	Zostera Biotopes
Vol II	Intertidal Sand and Mudflats & Subtidal Mobile Sandbanks
Vol III	Sea Pens and Burrowing Megafauna
Vol. IV	Subtidal Brittlestar Beds
Vol. V	Maerl
Vol. VI	Intertidal Reef Biotopes
Vol. VII	Infralittoral Reef Biotopes with Kelp Species
Vol. VIII	Circalittoral Faunal Turfs
Vol. IX	Biogenic Reefs.

Each report was produced initially by appropriate specialists from the wider scientific community in the respective subject. These reports have been reviewed through an extensive process involving experts from academic and research institutions and the statutory nature conservation bodies.

The results of these reviews are aimed primarily at staff in the statutory nature conservation bodies who are engaged in providing conservation objectives and monitoring advice to the marine SAC management schemes. However these reports will be a valuable resource to other relevant authorities and those involved in the broader network of coastal-marine protected areas. In order to reach out to a wider audience in the UK and Europe, a succinct 'synthesis' document will be prepared as a complement to the detailed 9-volume series. This document will summarise the main points from the individual reviews and expand on linkages between biotopes, habitats and sites and related conservation initiatives.

These reports provide a sound basis on which to make management decisions on marine SACs and also on other related initiatives through the Biodiversity Action Plans and Oslo and Paris Convention and, as a result, they will make a substantial contribution to the conservation of our important marine wildlife. Marine conservation is still in its infancy but, through the practical application of this knowledge in the management and monitoring of features, this understanding will be refined and deepened.

We commend these reports to all concerned with the sustainable use and conservation of our marine and coastal heritage.

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EXECUTIVE SUMMARY

In this review we assess the importance of intertidal reef biotopes with respect to the United Kingdom Marine Special Areas of Conservation project, together with the implications of the physical characteristics and the sensitivity and dynamics of biological communities found on rocky shores for their conservation and management. Reefs are listed as a conservation feature in Annex I of the EC Habitats directive. We take this term to include all intertidal rocky shore communities. Communities on intertidal reefs are sensitive to impacts, such as oil spills, yet are accessible and relatively well understood. Monitoring intertidal reefs is therefore likely to be cost effective and informative. The extensive distribution and fundamental nature of intertidal reefs means that the habitat itself is not under threat from human activities.

Rocky intertidal habitats are ubiquitous on coasts of the British Isles, forming the greatest part of the length of western coastlines. Rocky shores are not in short supply nor is their physical structure particularly sensitive to anthropogenic impact. Erosion and damage to coastlines often creates new areas for colonisation by rocky shore species. Even where rocks are rare or absent, such species can be found on all manner of man-made and natural hard substrata. Tides and waves create the zone at the interface between land and sea characterised by periodic inundation. Most species found in abundance on rocky shores at low tide are permanently resident, while mobile species enter and leave with the tide.

Environmental requirements and physical attributes

The primary determinant of shore zonation patterns for marine organisms is the vertical gradient of increased stress associated with increased emersion. A stress gradient runs in the opposite direction for terrestrial species. Along and between shores, the degree of wave action is also an important determinant of community structure. The location of a shore on these two gradients is a fundamental habitat characteristic with profound implications for the type of species it will support. The presence of particular species will be also be influenced by the location of the shore in their geographical range. The structure of the substratum is a major habitat characteristic. Surface area and the number of available microhabitats generally increase with topographical complexity, providing habitats for a larger range of species and reducing the negative effects of species interactions. This results in greater biodiversity in more topographically complex habitats.

Biology and ecology of rocky shores

While physical factors clearly influence the distribution and abundance of species on rocky shores it is the interaction between physical and biological factors that is responsible for much of the structure and dynamics of rocky shore communities. The most immediately obvious pattern in these communities is that of vertical zonation. The Stephenson's three zone classification provides a useful framework for studying the zonation patterns seen on UK shores, although it does not work well on sheltered, canopy dominated shores. Patterns of distribution on rocky shores have attracted ecologists for many decades with the consequence that the structure and dynamics of such communities are thought to be well understood.

Rocky shore communities are frequently unstable due to the combined effects of physical disturbance, competition, grazing, predation and recruitment variation. Many communities are dominated by a small number of species which occupy the majority of available space. In some communities the structure is strongly influenced by the presence of a few important consumers which control the abundance of the species competing for space. Presence and abundance of these key species can be used to characterise the general condition of communities.

Rocky shore communities are highly productive and are an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems.

Rocky shores can often be highly complex ecosystems, due to high levels of habitat variation over short distances. Homogeneous surfaces are often dominated by a few abundant species. Most of these species, particularly algae and mussels provide microhabitats for other, less common species. Cryptic microhabitats are characterised by communities quite different from those seen on open rock and are an important source of biodiversity. Increasingly benign physical conditions for marine species results in increasing species diversity and biomass towards the low shore.

Susceptibility to natural events and human activities

Long-term monitoring has shown that some rocky shore communities can be highly variable in time. Natural variations in time are thought largely to be due to variations in the supply of planktonic propagules and survival subsequent to settlement, influenced by biological interactions and direct climatic effects. Cover of macroalgae, particularly *Fucus vesiculosus* on moderately exposed shores, can vary naturally within a decade from very low to complete cover. Different biotopes of the MNCR scheme are assessed for their likely stability in this report (Appendix 1). Populations of some rocky shore species are particularly responsive to temperature changes, particularly those at the edges of their latitudinal ranges, and have been used as indicators of climatic change. Others are particularly sensitive to contaminants, notably dogwhelks driven locally to extinction by tributyltin leached from anti-fouling paints.

Rocky shore communities are sensitive to a range of environmental impacts from chronic low impacts such as human recreational activities, harvesting and sewage pollution, through chronic catastrophic effects of biocides such as tributyltin, to acute factors including red tides and oil spills and introduced species. Generally, the effects of chronic impacts on rocky shores are reversible provided the disturbance is stopped. Recovery from acute impacts is also possible but may take much longer depending on the scale of the impact. Opportunistic studies following acute impacts such as the *Torrey Canyon* disaster have improved our understanding of the processes of recovery in rocky shore communities. Recovery is a return to the normal community structure and dynamics. Baseline information is desirable for a confident statement of the status of recovery towards normality for any particular shore.

Impacts on a few species within a rocky shore community can potentially affect the structure of the whole community, especially when the activities of those key species have a strong effect on community structure (see Chapter III).

Not all anthropogenic impacts have a negative effect on the biodiversity of rocky shores., Coastal constructions may represent a threat to the extent of sedimentary shores but provide suitable habitats for rocky shore organisms. Other artificial substrata and some introduced species may have positive effects.

The management of SACs should aim to minimise impacts wherever possible. Where local needs would generate such impacts, consideration of the likely resilience of rocky shore species and communities to those impacts should allow informed decisions. This presents a particular difficulty in the case of recreational impacts. Conservation efforts depend heavily on public co-operation and the benefits of allowing public access are considerable. Management schemes should aim to minimise the damage caused by visitors without placing excessive restrictions on the public.

Monitoring and surveillance

Many options exist for the monitoring and surveillance of rocky shore communities. Many methods exist for measuring physical and biological characteristics of rocky shores. Rapid assessment techniques can generate semi-quantitative data relatively quickly and these are discussed. Survey design in a hypothesis-testing framework is desirable. Recommendations for methodology tailored to requirements of surveys and monitoring schemes are made in Chapter VI.

The effective management of Marine SACs and other conservation areas will depend on well designed and executed surveillance and monitoring schemes. Surveillance is required to determine whether the ecology changes in response to particular events or activities and monitoring is required to determine whether management of the site is effective. Rocky shores are the most accessible marine habitat and can be surveyed cheaply and non destructively. Rocky shores can therefore be used to assess the general condition of coastal ecosystems.

Many rocky shore communities undergo a great deal of natural change. It is therefore important that monitoring and surveillance schemes should be able to distinguish between natural and unnatural changes. Although the MNCR biotope classification allows shores to be characterised at a given instant, it is not designed to monitor natural changes in community composition. Unless the effects are visible and obvious, such as direct mortality in response to oil coating, natural changes can only be distinguished from anthropogenic impacts with a monitoring scheme covering a range of sites. We advocate a hierarchical approach: starting with broad scale quantification and qualitative description but using a quantitative approach which will allow the application of statistical analysis whenever possible.

Existing sampling and analysis techniques are sufficiently advanced to allow very detailed surveillance and monitoring. However, we recognise that what can be achieved within SACs will be limited by the personnel and time available. Many of the proposed SACs are remote from scientific centres. Monitoring schemes should therefore be planned with careful attention to the information required and the resources available. Compromises must be made between the scale of a study and the level of spatial and biological detail. When the aim of a study is to produce detailed inventories of species, or to assess species richness, thorough assessment of each species must be performed. However, most surveillance and monitoring requirements will be met by focusing on the abundance of between 15 and 30 key species. A compromise must be reached between the number of species used and the number of sites or levels within each site.

Semi-quantitative abundance scales provide less detail than direct counts of species abundance. However, they allow much faster assessment of a site. We recommend the use of abundance scales within a stratified random sampling design. Fresh abundance estimates for each species should be made during each survey. Timed searches may be more appropriate for rare species. Fixed quadrats are recommended for monitoring the condition of rare sessile species.

Photography of shores is recommended wherever possible as a quick and convenient record of the gross features of the shore. All monitoring of rocky shores will require some element of physical surveillance in order to relate the observed community structure to such factors as shore height, exposure and rock type. When surveying is part of a large scale mapping programme (for example, biogeographic mapping of the UK coastline), physical information may be provided by Ordnance Survey maps, Admiralty charts or remote sensing. Sampling sites might be about 100kms apart and be visited once a decade. Photographs of the shore will provide a record of the dominant space occupying organisms in each zone. More detailed information will be gained by conducting surveys of the abundance of between 15 and 30 key species at three levels on the shore (high, mid and low).

Within SACs, maps should be constructed of biotope or species distributions at finer scales. It is recommended that sites are located 10 km apart and are visited once a decade for surveillance purposes. However, yearly site visits are recommended to monitor the condition of shores within SACs. These visits should be made between mid summer and early autumn. Surveys should be conducted along fixed transects. Vertical transects should be established and physical surveys conducted along them at the beginning of the monitoring period. The position of these transects can be relocated on return visits either with detailed photographs or using fixed markers. Again, abundance surveys for 15 to 30 key species should be conducted but in 3 to 6 shore levels with replicated transects. Where the use of quadrats is not valid, abundance scales can be used.

Human activities occurring within or close to SACs should be assessed for potential impacts on shore communities. Surveillance can be conducted using the methods described for mapping within SACs. However, sites should be chosen on the basis of their proximity to the putative impact. Site visits should occur once or twice each year.

Low level chronic pollution might be detected through changes in the abundance of selected species. However, specific indicators might be identified through targeted research. Surveillance may result in some impact on the shore community. This can be minimised through the use of non-destructive sampling and care taken to avoid disturbing flora and fauna during fieldwork.

Requirements for further research

Progress in understanding the dynamics of rocky shore communities will continue in the academic community through experimental studies, and the analysis of survey and monitoring programmes. SACs should be ideal sites for studying the ecology of communities unaffected by anthropogenic disturbance. Close co-operation between conservation managers of SACs and the scientific community should be encouraged wherever possible, and especially where research facilities and expertise are locally available.

While the ecology of communities on uniform surfaces has been well studied, more information is needed for communities associated with rock pools, crevices, caves, overhangs, boulders, mussel beds and algal canopies. The large scale effects of local hydrography through effects on recruitment to rocky shore communities are poorly understood. Continuing research into the effects of novel contaminants and other impacts is also needed, and could be supported by survey and monitoring efforts at SACs. Close attention to statistically-valid designs of monitoring and survey schemes will vastly improve their power to detect anthropogenic impacts. New methods for the rapid assessment of rocky shores need to be developed and validated in the context of current more labour-intensive systems.

Synthesis and application in the management of SACs

The main conservation value of rocky shores lies in their accessibility, producing considerable amenity value for both recreation and education. Ease of public access to these marine habitats could be used positively to promote the conservation objectives of marine SACs. While increased visitor pressure can have a localised effect on rocky shore communities, education should reduce this impact and ultimately offset it through a greater awareness of visitors to the sensitivities of their environment. Rocky shores are easily and efficiently surveyed. Monitoring of rocky shore communities is recommended to assess anthropogenic impacts and the general condition of coastal ecosystems. Since many littoral species reach their geographical limits on British shores, any ecological monitoring of SACs may reveal effects and consequences of climate change.

Finally, rocky shores communities have a generally robust capacity to recover naturally from anthropogenic impacts because of the rapid rate of arrival of propagules from unaffected areas. The rate of recovery does, however, depend on the scale of the impact and the ability of the component species to recolonise impacted areas. Attempts in the past to intervene after an impact have usually proved disastrous.

I.
INTRODUCTION

The purpose of this review is a brief synopsis of scientific understanding and expert opinion on rocky shores under the headings given by each chapter title. The intended audience for the report is conservation practitioners. The aim is therefore to provide the reader with sufficient information on the value of and threats to rocky shores in order to identify conservation objectives and choose efficient, workable methods for monitoring shores and implementing conservation measures. The UK Marine SAC project is discussed as a means of protecting marine environments.

A. NATURE AND IMPORTANCE OF ROCKY LITTORAL HABITATS

Annex I of the EU Habitats Directive identifies reef habitats as natural features which are important in conservation terms. In the present context, the word 'reef' is used simply to imply a hard substratum type. Thus the term intertidal reefs refers to rocky littoral habitats, commonly described as rocky shores. This report aims to provide a synthesis-oriented scientific review of rocky shore biotopes. This includes each of the littoral rock habitat complexes described by Connor *et al* (1997) with the exception of biogenic reefs (e.g. those produced by *Sabellaria* species) which are the subject of a separate marine SAC review (see Holt *et. al.*, 1998). It also covers those sublittoral rock biotopes which are found in the sublittoral fringe.

Rocky shores are the major habitat on most of the coast from the Isle of Wight around Wales and Scotland to Flamborough Head. They are of considerable conservation importance as sites of high biodiversity. Most importantly they are well studied and understood using both observational and manipulative field experimental approaches. In the British Isles we are particularly fortunate to have a eloquent descriptive account of most types of rocky shore in Lewis (1964). We also have the extensive biogeographic surveys of major species made in the 1950s (e.g. Crisp and Southward, 1958). This has been followed by much experimental work including pioneering limpet removal experiments (Jones, 1948; Lodge, 1948) reviewed in Southward and Southward (1978) and Hawkins *et al* (1992) and summarised in recent textbooks (Hawkins and Jones, 1992; Raffaelli and Hawkins, 1996; Little and Kitching, 1996).

This work in both Britain and overseas has highlighted the major environmental gradients on shores (tidal elevation, wave action) and the importance of biological interactions in structuring shore communities. In the British Isles the functional influence of key species, such as limpet grazing on exposed shores and the structural role of the algal canopy on sheltered shores, have been demonstrated by field experiments (see Hawkins *et al*, 1992 for review). Biogeographic variation around Britain is also well known for most important species. Recruitment variation has also been shown to be an important factor in the dynamics of rocky shore systems (see Raffaelli and Hawkins, 1996 for review).

Communities of species on rocky shores are sensitive to a variety of both acute (e.g. oil spills) and chronic impacts (e.g. TBT-based paints, recreational activities). The responses of communities to these impacts is well understood enabling conservation measures to be proposed. The accessibility of rocky shores means they have a key role to play in conveying a strong conservation message to the general public. Many voluntary reserves use rocky shores in this way (e.g. Kimmeridge, Wembury, St Mary's Island). Their accessibility and two-dimensional structure makes them suitable for extensive surveillance and monitoring. Some rocky shore species are good indicators of climatic change. Monitoring marine protected areas with a wide spatial extent would enable detection of effects of climatic change (Southward, Hawkins and Burrows, 1995).

B. DISTRIBUTION AND STATUS OF ROCKY LITTORAL HABITATS

Rocky shores are an abundant feature of the coastline of the UK, especially on western coasts where exposed bedrock predominates on the coast. While the substratum of most vertically-orientated shores is composed entirely of continuous bedrock, many less steeply shelving shores have more broken rock forms, such as large boulders and isolated reefs. In many places rocky substrata are interspersed with particulate substrata, from cobbles through pebbles to gravel, sand and mud. The presence of mobile particulates, especially sand and shingle, can have a severe scouring effect on sessile forms on rocky substrata and consequent effects on community structure. Rock type has relatively little direct effect on the organisms which live in rocky areas, except where the rock type is extremely friable or porous, such as chalk. The major influence of the geological formation on rocky shore communities is indirectly expressed through the topography of the substratum. Bed form may be set by the susceptibility of the rock to erosion, the angle of sedimentary strata, and the interplay of these factors with the geography of each local region (wave exposure etc.).

Unlike sedimentary (dune systems) or biogenic structures (salt marshes, maerl beds), the existence of rocky littoral reefs in the U.K. is not under threat. Anthropogenic effects such as coastal development or climate change may temporarily alter the rocky substrata but will not significantly alter the area available for colonisation. However, certain types of rocky shores are rare in the UK. These include sheltered limestone and upper estuarine bedrock shores. The scarcity of these shore types means they are potentially vulnerable to localised impacts.

C. THE MNCR BIOTOPE CLASSIFICATION

The Marine Nature Conservation Review (MNCR) has developed a system of classification of shallow-water benthic marine communities based on surveys of a very wide range of subtidal and intertidal sites and the relevant literature. The MNCR biotope scheme (Connor *et al*, 1997) allows the classification of areas according to a combination of biological and habitat characteristics. Biotope maps are being produced for areas of conservation importance.

The hierarchical structure of the scheme is designed for classifying areas of seabed based on their physical and biological characteristics (Connor *et al.,* 1997). Larger-scale differences among shores, including intertidal reefs, are effectively represented at the highest level of division by the 28 habitat complexes. Biological communities thereon are recognisable in the 60 biotope complexes into which these habitat complexes are subdivided. Further subdivision of these complexes results in the biotopes themselves (see Appendix 1 for biotopes of relevance to rocky shores).

Some rocky shore communities are highly variable in space and time (mussel-barnacle mosaics, Lewis, 1976, *Fucus*-barnacle mosaics, Hartnoll and Hawkins, 1985; Hawkins *et al*., 1992) while others are very stable (beds of *Ascophyllum* spp.; barnacle-limpet communities on verticals). In consequence classification of rocky shores according to the biotope scheme from a single site visit should be attempted with caution. Many of the biotopes listed in the scheme may represent stages on continua in either space or time.

As an aid to the rapid assessment of shores the biotope classification has value for early management decisions. Broader application must account for the known limitations. Many communities on intertidal bedrock, and especially on unstable boulder shores, may suffer high levels of physical disturbance. Biological communities in such habitats may reflect successional stages towards a climax rarely achieved. Topographically heterogeneous shores may contain a mosaic of interspersed community types, leading to major problems of classification to a single biotope. Finally, a single biotope class for a shore community may mask information on individual species with potentially important consequences for conservation. Disappearance of sensitive species, such as the dogwhelk *Nucella lapillus* in areas of high levels of tributyltin (p 42), may not result in a change in biotope class.

D. KEY POINTS

- Reefs are listed as a conservation feature in Annex I of the EC Habitats directive and include all littoral rocky shore communities. ‘Littoral’ includes the intertidal regions named in the title, as well as levels above and below the extreme limits of the tide where the biota is strongly associated with the intertidal zone.
- Rocky shores are a major habitat on the UK coast, especially in the west.
- Communities on intertidal reefs are sensitive to impacts, such as oil spills, yet are accessible and relatively well understood. Monitoring intertidal reefs is therefore likely to be cost effective and informative.
- The extensive distribution and basic nature of intertidal reefs means that the physical structure of most rocky shore habitats is not generally under threat from human activities.
- Single-visit application of the MNCR biotope classification does not allow for natural changes in the abundance of species over time. Natural changes could easily cause a given area to progress through a number of biotopes over time. Attribution of causes of changes requires a more intensive monitoring protocol.

II.
ENVIRONMENTAL REQUIREMENTS AND PHYSICAL ATTRIBUTES

A. INTRODUCTION

Rocky shores, by definition, occur where land and sea meet on a hard substratum. Where there is a considerable tidal range, the shore has an intertidal zone which is subject to cycles of immersion and emersion. Although the habitats and communities under consideration in the present report are often referred to as intertidal, they do not always conform to the strict definition of the term. Tides may be more or less absent in some areas, with characteristic rocky shore species occupying a narrow range which is wetted by waves or swell. As described later in this chapter, some of these species can be found many metres above the highest tide level on exposed cliffs. Biological communities occupying shore levels that experience both exposure to the air and wetting by the sea are described as **littoral.**

The onshore currents and rising tides supply the shore with particulate organic material, an important food source. Rocky shores are characterised as ‘eroding’. Sediment and debris are removed by waves and retreating tides. Sediment may, however, accumulate in crevices or under dense algal canopies. Wave action usually ensures that rocky shores are well supplied with dissolved oxygen. The shallow waters allow light penetration, so primary production is rarely light limited.

Two major physical gradients (vertical emersion gradient and horizontal wave action gradient) determine the types of community which a shore can support. Physical characteristics of the substratum are also important with increasing complexity leading to greater biodiversity. A number of physical factors relating to the geographical position of the shore also have a strong influence on the biota present.

B. PHYSICAL GRADIENTS

On gently shelving rocky shores, the littoral zone may extend for hundreds of metres. However, rocky shores are often steeply shelving and the littoral zone therefore occupies a few tens of metres or less. The interface between air and water along with the action of tides and waves result in a vertical emersion gradient of increasing exposure to air from low shore to high shore. A horizontal gradient of exposure to wave action also exists both among microhabitats within shores and among different shores. The interaction between these gradients is of prime importance in determining the type of organisms that any area of hard shore will support. Clear, well studied, patterns of zonation of flora and fauna exist on rocky shores as a result (Stephenson and Stephenson, 1972; Lewis, 1964; **Figure 4** on p28, from Ballantine, 1961).

1. The Vertical Emersion Gradient

Compared with subtidal habitats, conditions fluctuate much more in the littoral zone. The sea provides a buffer, damping temperature fluctuations and maintaining a steady concentration of salts and nutrients. At the interface between land and water, organisms spend part of their time immersed in the sea, or at least splashed by its spray, and part of their time in contact with the air, with a vertical gradient of emersion up the shore. Since most littoral organisms are of marine origin, this results in a unidirectional stress gradient. Air temperatures commonly fluctuate by 10 to 20°C in a single 24 hour period whereas sea temperatures usually fluctuate by less than 10°C in a year. In polar and boreal regions, intertidal air temperatures might fall as low as - 40°C while the sea is never colder than about -0.2°C. Salinity in pools and crevices in the littoral zone can vary considerably with evaporation and dilution by rain. Water-borne food, nutrients, dissolved oxygen and the protection from desiccation and extreme temperatures conferred by immersion, are available for less of the time at increasing shore heights. In temperate zones, the risk of desiccation due to heat and low humidity is the most significant stress. Extreme cold is a more important stress at higher latitudes. A gradient of increasing stress to terrestrial organisms due to immersion runs down the shore. These vertical stress gradients have important ecological effects on rocky shores, contributing to the clear zonation patterns within the biological community (see Chapter III).

Tidal ranges vary from 0.5m to 12m in the British Isles. Greater tidal ranges result in more extensive littoral zones. However, even in the absence of tides, a zone exists in which the sea laps against the shore or waves break and splash (the ‘splash zone’). The form of tides also varies along the U.K. coast: most are semi-diurnal with two low tides and two high tides every 24. hours. In some parts of the British coast, particularly in the region between Portsmouth and the Isle of Wight, double low and double high waters can occur resulting in very low water stands on spring tides

The time of low water varies with geographical position. This will determine the type of stress suffered by organisms when exposed. This is particularly relevant to low shore species which rely on the sea to protect them from environmental extremes as much as possible. Desiccation stress will be most severe when spring tide low water occurs at around midday, particularly if exaggerated by a double tide (see Section II.B.1). The geographical range of species can be limited by currents. The sea urchin, *Paracentrotus lividus* occurs on the West coast of Ireland but does not establish on shores in England or Wales. Conversely, *Patella depressa* is common around southern England and Wales but absent from Ireland (Southward and Crisp, 1955).

2. The Horizontal Wave-Action Gradient

The structure of ecological communities on rocky shores is also affected by a horizontal gradient of exposure to wave action, from sheltered bays to exposed headlands. The extent of wave action on a particular shore is determined by the aspect to prevailing winds coupled with the ‘fetch’: the distance over which winds blow. Shores with a long fetch have heavy wave action because the wind has a greater distance to generate the height of the waves. Such shores may also receive swell on windless days, resulting from distant storms. Oceanic islands and headlands on ocean coasts therefore have the most exposed shores. Bays in enclosed water bodies such as sea lochs and the Irish Sea will experience the least wave action, especially when they face away from the prevailing wind. The list of candidate SACs for the UK includes rocky shores at both very exposed (St. Kilda, Papa Stour, Lundy) and very sheltered (Loch Duich, Loch Alsh, Loch Long) sites.

Exposure to wave action affects the distribution of organisms. Increasing exposure reduces siltation and increases the supply of dissolved oxygen and particulate food, favouring certain sessile, filter-feeding species. At the same time, increasing exposure carries an increased risk of dislodgement and physical damage, limiting the range of susceptible and physically fragile species. Morphological differences can be observed between members of the same species from wave-exposed and sheltered sites. For example, dogwhelks from wave-exposed shores have thinner shells with larger apertures than those from sheltered shores. Wave-exposed morphs are better at clinging to the substratum while sheltered morphs are better protected against predation by crabs.

In contrast to the unidirectional nature of the vertical emersion gradient, the horizontal gradient is less well defined: some species do well on wave-exposed shores, some do best in shelter and others under intermediate conditions. However, the degree of exposure or shelter required by a species may vary along its geographical range. For example, the limpet *Patella vulgata* is restricted to wave-exposed shores in Norway and sheltered shores in Spain while in Britain it is found on both shore types.

3. The Interaction Between Emersion and Wave Action

Each of the two gradients described above has its own effect on community structure. The degree of exposure to wave action can modify the extent of the vertical gradient. As wave action increases, so too does the amount of spray produced. Waves with greater amplitude break at higher shore levels, showering still higher areas with spray. At very exposed sites, shore levels well above the highest tide level may be regularly wetted by the action of waves. It is not uncommon to find high shore species many tens of metres above the theoretical tidal limit on very exposed cliffs (Lewis, 1964). Species which are referred to as intertidal may therefore exist above the theoretical extent of high water springs on a calm day. Any useful assessment of the shore community must include these organisms.

C. TOPOGRAPHICAL STRUCTURE OF THE SUBSTRATUM

Hard shores in the UK are composed of a large range of rock types, dependent on the geology of each region. Man-made surfaces such as coastal defences, harbour walls and pier pilings also provide a substratum for rocky shore species. The community present on a rocky shore will be strongly influenced by the structure of the substratum at several spatial scales.

1. Rock hardness

Hard, igneous rocks such as basalt and granite along with fine sedimentary rocks such as siltstone and shale will drain and dry rapidly as the tide recedes. More porous rocks such as sandstone and chalk retain water for longer, reducing desiccation stress. Hard rocks provide a more secure anchorage for large plants and animals such as fucoids and limpets. Animals such as piddocks are able to burrow into chalk and other soft rocks as can endolithtic microalgae, particularly cyanobacteria. Many littoral organisms are more likely to settle on some rock types than others. Proposed explanations for this include the surface roughness of the rock and the ability of rocks of different types to sequester and partition solutes (Holmes *et al.*, 1997).

2. Slope and Complexity

Rock type influences the slope and topographical complexity of the shore, and slope determines the area available for littoral species. Barnacles and limpets are successful on steep shores, while mussels and seaweeds are more common on gently sloping or horizontal shores. The colonisation of shores by animals is an active process in those species with motile larvae, whereas algae rely on the retention of passive spores. Therefore, algae are better able to colonise more horizontal surfaces. Increasing topographical complexity also increases space and the number of microhabitats available. These factors have a strong influence on biodiversity.

Numbers of species and abundance increases with topographical complexity (Kostylev *et al.*, 1996). Greater abundance results from a larger surface area while the number of species present is influenced by the range of microhabitats available. Tiny pits in the rock may provide shelter for juvenile littorinids and other small species. Larger cracks and crevices provide shelter for mobile predators like dogwhelks. Crevices also collect sediment and trap air. This provides a favourable environment for a highly specialised fauna of burrowing worms and air-breathing arthropods. Air-breathing animals include centipedes, millipedes, beetles and pseudoscorpions, and pulmonates such as *Onchidella celtica*, foraging only during emersion and taking refuge in air pockets during tidal immersion. Crevices also provide a daytime retreat for nocturnally active invertebrates of marine origin, such as members of the genera *Lineus*, *Eulalia*, *Ligia* and *Orchestia*. Hypoxic silt accumulating in deep crevices allows 'soft sediment' biota such as *Cirratulu cirratus* to live on rocky shores.

3. Mixed Substrata

Rocky shores might consist mainly of bedrock or they may be a mixture of bedrock and boulders, cobbles or pebbles. Boulders and smaller rock fragments can cover the whole shore or they can occur in lower densities on sediment shores. Bedrock itself is rarely smooth. Usually, there will be some form of three dimensional structure. Conglomerates have rounded humps where pebbles are present in the rock with troughs between and hollows where hard pebbles have been removed. Basalt forms smooth, regular columns which can collapse to form boulders. Limestone can form extensive ledges dotted with eroded pools. Soft rocks like chalk are usually rounded by erosion while slate shores consist of slabs with angular gullies. Each type will have its own degree of topographical complexity according to the three dimensional features present: cracks, crevices, overhangs, folds, rock fragments and pools.

4. Rock microhabitats

a) Rock pools

Rock pools are a well known feature of many rocky shores although their ecology is less well understood than that of bedrock (see Chapter VII). Pools provide an intertidal habitat for obligate water dwellers including many species of fishes. They also support low-shore organisms, such as seaweeds and anemones, at higher levels than they would otherwise be found. However, those pools at higher shore levels are subject to physical and chemical fluctuations which would not be experienced in the sea (Morris and Taylor, 1982). Pools at about the level of neap tide high water will be separated from the sea for continual periods of about 11 hours. Higher up the shore, pools experience several days without inundation (Naylor and Slinn, 1958). Temperatures in these small bodies of water change in response to air temperatures more rapidly than those in the sea. Water evaporates from pools and rainwater and freshwater runoff collects in them, causing salinity fluctuations. Fluctuations in oxygen content and pH also occur with a diurnal cycle. During the daytime, plants photosynthesise, saturating the water with oxygen and supersaturation is not uncommon. During the night, a net uptake of oxygen and production of carbon dioxide occurs. Oxygen concentration drops and pH falls as a result.

b) Boulders

Boulders have an upper surface similar to bedrock and, if stable, the tops are essentially the same as bedrock. Larger boulders will suffer less impact from waves on their shoreward sides. These sides may therefore be used by species at risk of dislodgement on more exposed surfaces. Boulders also have interstitial spaces below. Like crevices, these provide shelter for grazers and foragers. Mobile animals, including moulting crabs take refuge under rocks. Sediment will collect in the interstitial spaces and, often, the boulders rest on a sediment substratum. So, while communities on the tops of boulders are similar to bedrock shores, communities characteristic of sediment shores can be found below.

D. OTHER PHYSICAL FACTORS

The effects of emersion, wave-action and topography can be modified by other important factors. The geographical situation of any shore will determine the species which are available to colonise it, the degree of exposure to wave action and the stresses which organisms face at higher shore levels.

1. Temperature and Climate

In general terms, water temperature is the most important factor determining the distribution of marine organisms (Lüning and Asmus, 1991). Air temperatures are also important for littoral species.

a) Effects on limits of distribution

Many species reach the northern or southern limits of their distributions around the UK (Lewis, 1964). These limits can fluctuate, responding to fluctuations in climate (Crisp, 1964; Southward *et al*, 1995). Climate also affects the relative competitive abilities of species. This is particularly well illustrated by the barnacles *Semibalanus balanoides*, *Chthamalus stellatus* and *C. montagui*. On shores on the West coast of Scotland, *C. stellatus* and *C. montagui* are restricted to high shores as *S. balanoides*, the northern species, is competitively superior at these latitudes (Connell, 1961a,b). Further south in the UK, the two genera coexist in the mid shore (Crisp *et al*., 1981).

b) Degree of Disturbance

Climate can also affect the degree of disturbance suffered by shore communities. The extent of damage inflicted by water-borne debris increases as wave exposure and storms become more severe. At very high latitudes, where sea water freezes, ice scour can cause massive mortality of encrusting species during the winter months, though this rarely affects UK shores. Occasional hot summers can cause a disturbance on British rocky shores (e.g. Hawkins and Hartnoll, 1985)

2. Sediment loading

The supply of particulate organic matter to shores will depend on the local hydrodynamic regime, especially in relation to local processes of erosion and fluvial input. More of this material will arrive at the shore by advection when the prevailing wind blows towards the shore. Species tolerant to low salinities are able to colonise shores in estuaries and bays with substantial freshwater inflow. Offshore events help structure rocky shore communities not only by affecting levels of wave exposure and food supply but also by affecting the survival and onshore transport of larvae (see Chapters III and IV).

E. KEY POINTS

- Littoral communities are subject to far greater environmental fluctuations than subtidal communities, through the rise and fall of the tides, the impact of breaking waves and the greater variability of the terrestrial climate.
- For marine organisms, a vertical gradient of increased stress, associated with increased emersion exists on the shore. A stress gradient runs in the opposite direction for terrestrial species.
- The horizontal gradient of wave action is an important determinant of community structure.
- The position of any area of shore on these two gradients is a fundamental habitat characteristic with profound implications for the type of species it will support. The actual species present will be partly determined by geographical characteristics, specifically the shore's location in the geographical range of each species.
- The structure of the substratum is a major habitat characteristic. Generally surface area and the number of available microhabitats increase with topographical complexity, leading to greater biodiversity.
- Temperatures of the water and air are most important factors determining the distribution of littoral species. Many species reach the northern or southern limits of their distributions around the UK, and limits can fluctuate with climatic changes. The incidence of waves and storms also affects the degree of disturbance suffered by shore communities.
- Particulate organic matter and sediment loading on rocky shores can influence food supply and can be correlated with the survival and onshore transport of larvae

III.
BIOLOGY AND ECOLOGICAL FUNCTIONING

A. INTRODUCTION

Much of the community structure seen on rocky shores reveals the strong direct or indirect influence of physical factors. Clear vertical zonation patterns exist along the emersion gradient particularly on sheltered shores. The dominant mid-shore species in the UK change gradually from fucoids on sheltered shores to barnacles or mussels on exposed shores. However, rocky shores are also characterised by intense biological interactions including competition for space and grazing and predation which create free space. These interactions do much to shape the community from setting the limits of the vertical distributions of many species to affecting the persistence of species assemblages. It must be emphasised, however, that the direction and intensity of biological interactions is strongly influenced by the underlying physical gradient as well as offshore factors which, for example, have a strong effect via recruitment regime. The type and importance of biological interactions will also change on a biogeographical scale due to the over-riding influence of climate.

Many of the dominant species on rocky shores facilitate the presence of other species by providing space and shelter. At the same time, these dominant species often exclude their competitors. The rocky shore community is therefore structured by a complex array of positive and negative interactions between species. Some of the better understood consequences of these interactions are discussed as are the interactions between the rocky shore and other marine and terrestrial ecosystems.

B. ZONATION

1. Vertical Zonation

Rocky shores are often characterised by striking horizontal bands of species or species assemblages. A particularly good example is the neatly delineated stands of fucoid species on most sheltered UK shores (Lewis, 1964).

a) Stephenson and Stephenson's universal zonation scheme

An early and quite useful attempt to characterise the main zones seen on rocky shores was made by Stephenson and Stephenson (1949) and a much more detailed account of zonation on rocky shores in Britain and Ireland is given by Lewis (1964). The Stephensons identified three main zones common to many shores around the world (**Figure 1**).

- The upper zone, called the **supralittoral** fringe (also described as the littoral fringe by Lewis, 1964), is mainly characterised by lichens, cyanobacteria and small grazing snails, the periwinkles.
- The much broader **midlittoral** (eulittoral *sensu* Lewis, 1964) zone exists in the midshore and is dominated by suspension feeding barnacles and mussels.

- Finally, the narrow, low shore **infralittoral** (sublittoral *sensu* Lewis, 1964) fringe is dominated by red algae and kelps, species that usually extend into the permanently immersed **sublittora**l zone.

The width and upper limit of each zone generally increase as wave action becomes more intense (Lewis, 1964). The wave action gradient also affects the species which might be found in any zone. The Stephensons' three zone system can be applied to UK shores with some degree of wave exposure. On more sheltered shores, however, mid shore levels are often dominated by fucoids and the zones are less clear cut. The terminology used by Lewis (1964) is used more often in the U.K., for example it was adopted in the textbooks by Hawkins and Jones (1992) and Raffaelli and Hawkins (1996).

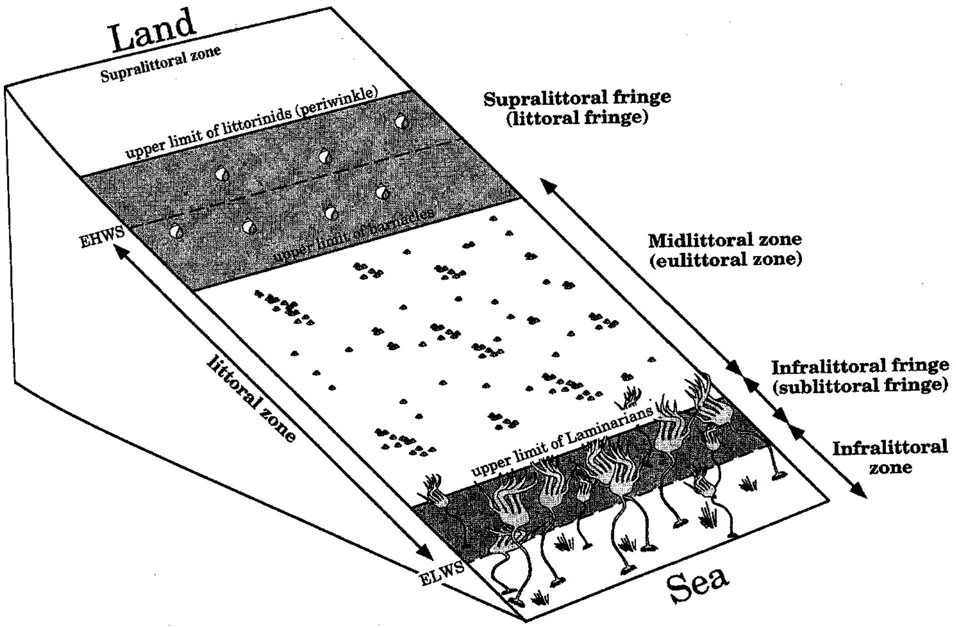

Figure 1 Stephenson and Stephenson's universal zonation scheme (from Raffaelli and Hawkins, 1996**)**

b) Zonation and direct responses to emersion

An obvious factor contributing to these zonation patterns is the emersion gradient (Section II.B.1 p17). It is well known that zonation of communities occurs along stress gradients. The best known examples are at the larger scales of altitude and latitude. An intuitive explanation for observed zonation patterns might be that the vertical distribution of each species is set by its tolerance to the stresses of prolonged exposure to the air during emersion and prolonged submergence during immersion (**Figure 2**). The causes of zonation have received a good deal of attention in laboratory and field studies dating back to the beginning of the 20th century (Baker, 1909). These studies have shown that **while physical factors directly influence the upper limits of the distribution of many species, biological interactions play a significant role in shaping zonation patterns. Biological factors act primarily on lower limits but can sometimes set upper limits.**

The majority of species found in the littoral zone are of marine origin. For these species, stress increases with shore height. It is usually true that higher shore species are more tolerant of the emersion stress than species found at lower shore levels (Norton, 1985). Physiological, behavioural and morphological adaptations allow high shore species to survive periods of emersion. However, low shore species are usually able to withstand periods of emersion greater than they experience in the field, even at the upper limits of their distribution. Many species do not occupy higher shore levels despite being able to tolerate the physical conditions found there.

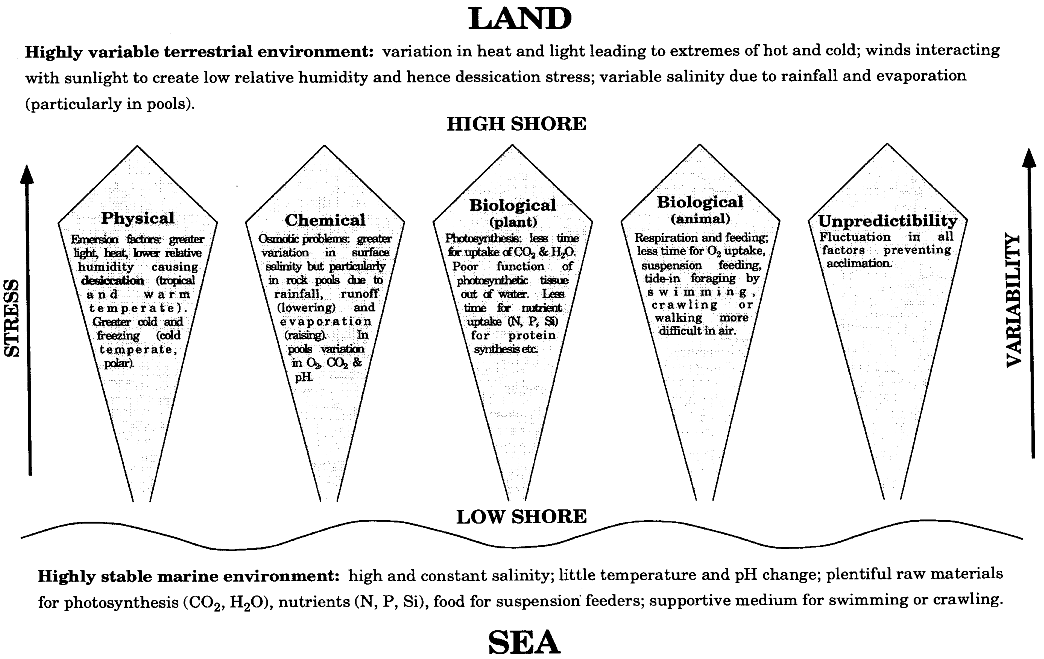

Figure 2. Stresses on the vertical gradient associated with tidal height. Arrows indicate increasing stress (from Raffaelli & Hawkins 1996).

Field observations have demonstrated that some species are killed by physical factors associated with emersion. For example, cyprids of the barnacle *Semibalanus balanoides* will settle above the upper limit of adult conspecifics during years of heavy settlement. If that settlement occurs during a hot spring, the cyprids die (Connell, 1961, Foster, 1971). If it occurs during a cool spring, the cyprids may survive until metamorphosis. Adults are more tolerant to emersion than cyprids. However, 'out-of-zone' adults eventually die as a result of desiccation stress during hot summers. Similarly, the high shore algae *Pelvetia* spp. and *Fucus spiralis* and even occasionally the midshore *Ascophyllum nodosum* can be killed during periods of hot weather (Schonbeck and Norton, 1978; Hawkins and Hartnoll, 1985; Norton, 1985).

The chlorophyte *Prasiola stipatata* is often abundant the high shore in the winter but dies back in the summer. During the same periods, several mid and low shore species, especially fucoids were not observed to die at their upper distributional limits. Thus, while it might directly set the upper limits for some sessile high and mid shore species (e.g. *F. vesiculosus* and *F. serratus*), physical stress on its own is not sufficient to determine the distribution patterns of every species. The experimental removal of higher shore algae can allow *F. vesiculosus* to extend its range upwards (Hawkins and Hartnoll, 1985). The reduced grazing pressure caused by the death of limpets following the *Torrey Canyon* oil spill led to an upward extension of low shore red algae and kelps (Southward and Southward, 1978). Thus the effects of grazing and competition are also important in defining the upper limits of species. Unpublished work in the U.K. (Boaventura and Hawkins) has shown that red algal turfs can be induced to extend higher up the shore if limpets are removed (see also Hawkins and Jones, 1992). Similar work was first done in Australia by Underwood and co-workers (Underwood, 1980; Underwood and Jernakoff, 1981). Further unpublished work (Hill, personal communication) has also shown that, in the short term, the kelp *Laminaria digitata* can grow higher up the shore if *Fucus serratus* is removed.

c) Biological Interactions controlling upper and lower limits: competition and predation

Biological factors are of great importance in determining the lower limits of rocky shore plants and sessile animals. Competition for space is perhaps the single most important biological interaction shaping rocky shore communities although grazing and predation also have significant effects. The dominant species on rocky shores are usually sessile and attached to the rock itself. Generally more of the available space is occupied at lower shore levels and new settlement can occur only when predation, grazing or physical disturbance removes previous occupants.

On Great Cumbrae the barnacle *Chthamalus montagui* is restricted to the high shore while the mid-shore is dominated by *Semibalanus balanoides.* Connell (1961a,b) found that *C. montagui* transplanted to lower shore levels were displaced by *S. balanoides* which grew faster and undercut or crushed the smaller species. However, when *S. balanoides* were removed, *Chthamalus* was able to survive and grow at mid-shore levels. Furthermore, *S. balanoides* was able to extend its range into lower zones when protected from predation by the dogwhelk, *Nucella lapillus*. It has subsequently been shown that competition from large fucoids and red algal turfs can prevent *Semibalanus* from extending into lower shore levels (Hawkins, 1983). *Pelvetia canaliculata* is usually prevented from spreading down the shore by competition from *Fucus spiralis*. However, both species can grow better at even lower levels than they are usually found (Schonbeck and Norton, 1980).

d) Behaviour: Habitat selection

Behaviour is an important factor determining the distribution of animals on the shore. Even sessile animals have mobile larvae which often preferentially settle close to adult conspecifics, thereby reinforcing existing zonation patterns. Limpets, dogwhelks and other mobile species can actively select areas of shore. Limpets rarely stray beyond their tolerance limits (Wolcott, 1973). Dogwhelks retreat to crevices and low shore levels to avoid the risk of dislodgement in storms (Burrows and Hughes, 1989).

e) General synthesis of factors setting limits

While the vertical zonation seen on rocky shores is clearly a response to the emersion gradient, physical factors do not set the upper limits of the distribution of all species. In general, the upper limits of most high shore species are set by physical factors. However, biological interactions, especially competition for space, grazing and predation can set the boundaries between many species at mid and lower shore levels, although their ultimate extension up the shore would be set by physical factors. In other words, physical factors set the ultimate upper limits to organisms of marine ancestry but proximate factors often prevent this physiological barrier from being reached.

2. Patterns in community structure along and between Shores

The wave exposure gradient also has a considerable effect on community structure, through the stresses and benefits experienced at different levels of wave energy (**Figure 3**). Certain species are well adapted to survive on exposed shores including the barnacles *Semibalanus balanoides* and *Chthamalus montagui*. Dogwhelks, which feed on barnacles and mussels are also more abundant on exposed shores. On exposed shores, eulittoral seaweeds are usually ephemeral or short turf forms. In contrast, the more foliose fucoids perform better in sheltered conditions where their presence reduces the abundance of barnacles in the mid-shore.

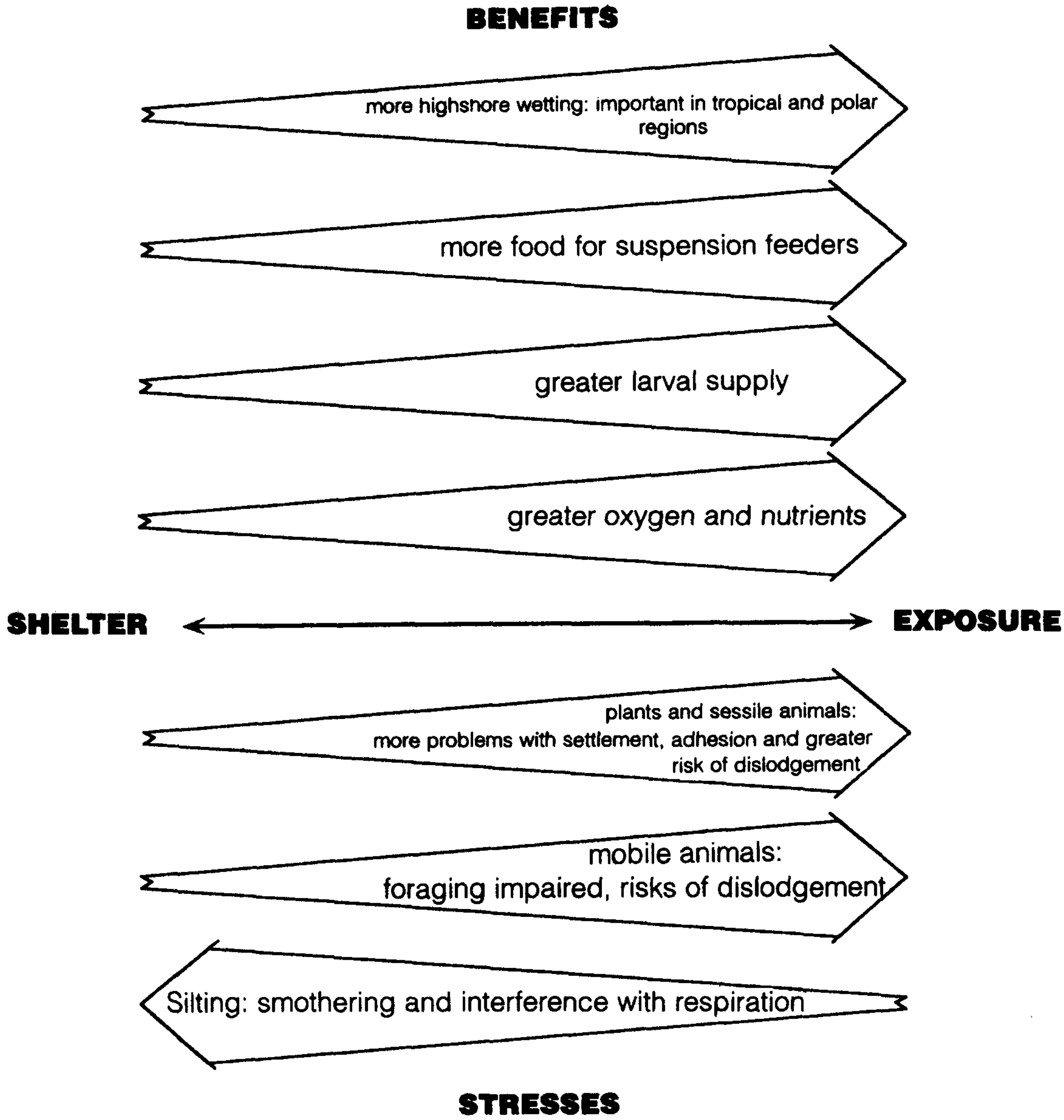

Figure 3. Beneficial and stressful changes along the wave action gradient (from Raffaelli & Hawkins 1996).

It is well known that most fucoids are prevented from establishing on exposed shores by limpet grazing (Jones, 1948, Southward and Southward, 1978, Hawkins and Hartnoll, 1983, Hawkins *et al*., 1992). The direct effects of wave action have been shown to be important for limiting recruitment of *Ascophyllum* spp. on more exposed shores (Vadas *et al*., 1990). Conversely, the factors responsible for excluding limpets and barnacles from sheltered shores are less well known. Larval supply, direct and indirect effects of canopies including competition from sub-dominant turf forming algal species, siltation, post-settlement predation have all been proposed

(Hawkins and Hartnoll, 1983, Hawkins and Jones, 1992, Hawkins *et al*., 1992) although the only attempt to test such ideas was made by Jenkins (1995).

Lower on the shore, *Alaria* spp. replaces *Laminaria digitata* in more exposed conditions, whilst *L. saccharia* predominates in shelter (**Figure 4**), particularly on unstable boulders being an annual. If *L. digitata* is removed on moderately sheltered shores, *L. saccharia* can be induced to colonise from shelter and *Alaria* spp. from exposure. This suggests that moderate shelter to moderate exposure are ideal conditions for sublittoral fringe kelp but that the more opportunistic species (*Alaria* spp., *L. saccaria*) are confined to sub-optimal conditions at either end of the wave exposure gradient (Hawkins and Harkin, 1985).

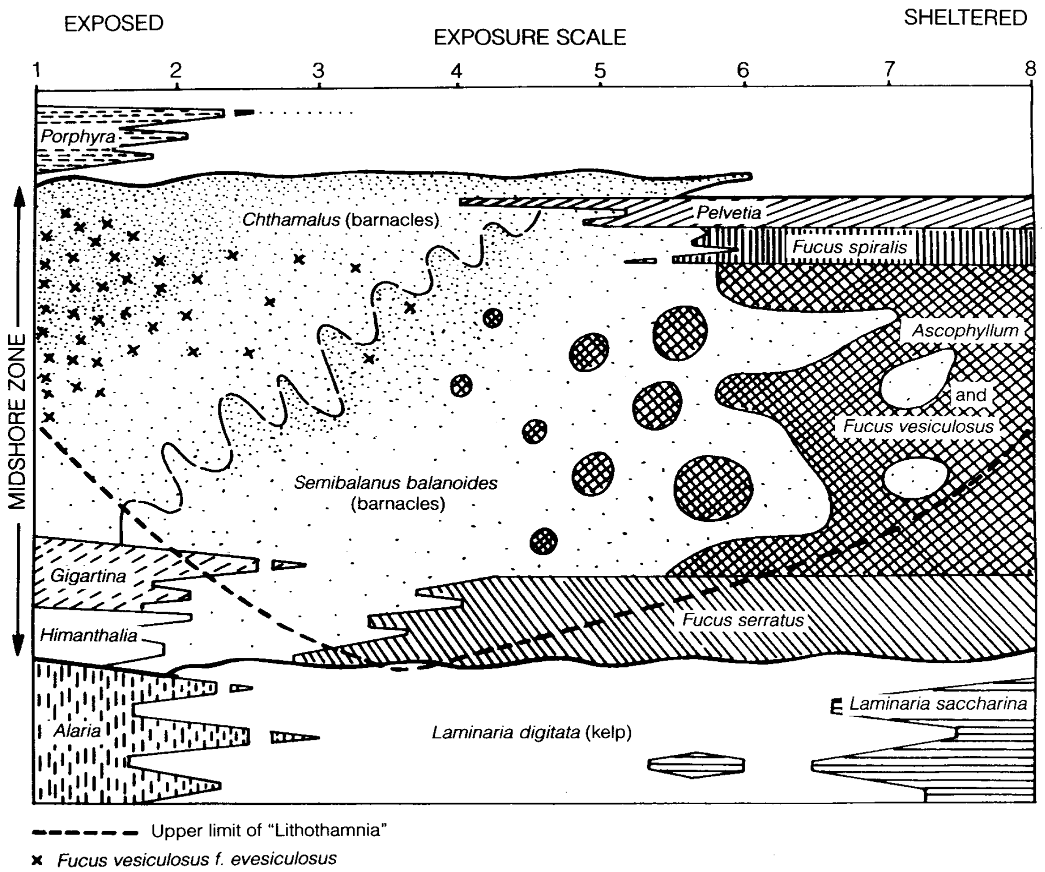

Figure 4. Schematic representation of the distribution of major organisms in relation to wave action and Ballantine's (1961) biologically defined wave-exposure scale based on shores in the Pembroke area of Wales (after Ballantiine, 1961, from Raffaelli and Hawkins, 1996)**.** (Note *Gigartina* is now *Mastocarpus*).

C. DYNAMICS OF POPULATIONS AND COMMUNITIES

The general patterns of zonation on rocky shores can be explained in terms of physical factors affecting the outcome of biological interactions. However, even clearly delimited zones of conspicuous space occupiers or canopy forming seaweeds also consist of numerous subsidiary species, the populations of which undergo fluctuations in space and time. Sheltered rocky shores generally have vary stable patterns of zonation over time. This can be true of steeper moderately exposed shores. Flatter moderately exposed shores are often characterised by highly dynamic communities with patches of one species giving way to another over time (see below). Communities on very exposed shores show dynamics caused by **physical disturbance events** which create space for recolonization.

Many fluctuations seen in rocky shore communities are due to biological interactions. However, all ecological communities are influenced to some degree by physical factors. The interaction of the emersion gradient, the wave exposure gradient and disturbance regime, the local hydrodynamic regime and the geographical position of the shore determine which species are likely to be found there. Thus any effect of species interactions (grazing, predation or competition) on community structure may ultimately depends on the influence of the physical environment on the species involved.

Stochastic (chance) events contribute greatly to variability in the community. The major cause of this type of variability is **stochastic variation in the supply of settling planktonic propagules** of key species in the community (Hawkins and Hartnoll, 1982; Gaines and Roughgarden, 1985; Hartnoll and Hawkins, 1985; Gaines and Bertness, 1992; see section E below), but the disturbance due to major climatic events (e.g. Crisp, 1964) or small-scale physical damage (Paine and Levin, 1981; Shanks and Wright, 1986) can have important effects.

1. Biologically-generated patches on moderately exposed shores

Moderately exposed rocky shores are often made up of a mosaic of patches, each cycling through a number of successional stages (**Figure 5**) and structured by a number of positive and negative interactions between the main species but with fluctuations generated by recruitment variation. The community is composed of such patches, each dominated by a particular species or group of species, which may give way to others and sometimes to bare rock over time. These have been particularly well studied on the Isle of Man (Burrows and Lodge, 1950; Hawkins and Hartnoll, 1983; Hartnoll and Hawkins; 1985, reviewed by Hawkins *et al.*, 1992). The limpet *Patella vulgata* is an important grazer, feeding on the young *Fucus vesiculosus* plants. Mature *F. vesiculosus* plants dislodge settling barnacles, *Semibalanus balanoides* as their fronds sweep over the rock. Juvenile limpets, which dislodge newly settled barnacles as they move, and dogwhelks, which are predators of barnacles, aggregate under mature clumps of *F. vesiculosus.* Thus, barnacles are scarce in patches dominated by mature *F. vesiculosus;* however, these patches last for only about 3 to 4 years. The sweeping action of *F. vesiculosus* fronds and the presence of limpets minimises the successful settlement of young fucoids. When the old plants die back, the sheltering limpets disperse and the bare rock is then colonised by barnacles. Limpet grazing is inefficient amongst mature barnacles; as a result, some fucoids are able to settle and survive. *F. vesiculosus* clumps appear amongst the barnacles, reducing barnacle recruitment and encouraging the aggregation of limpets.

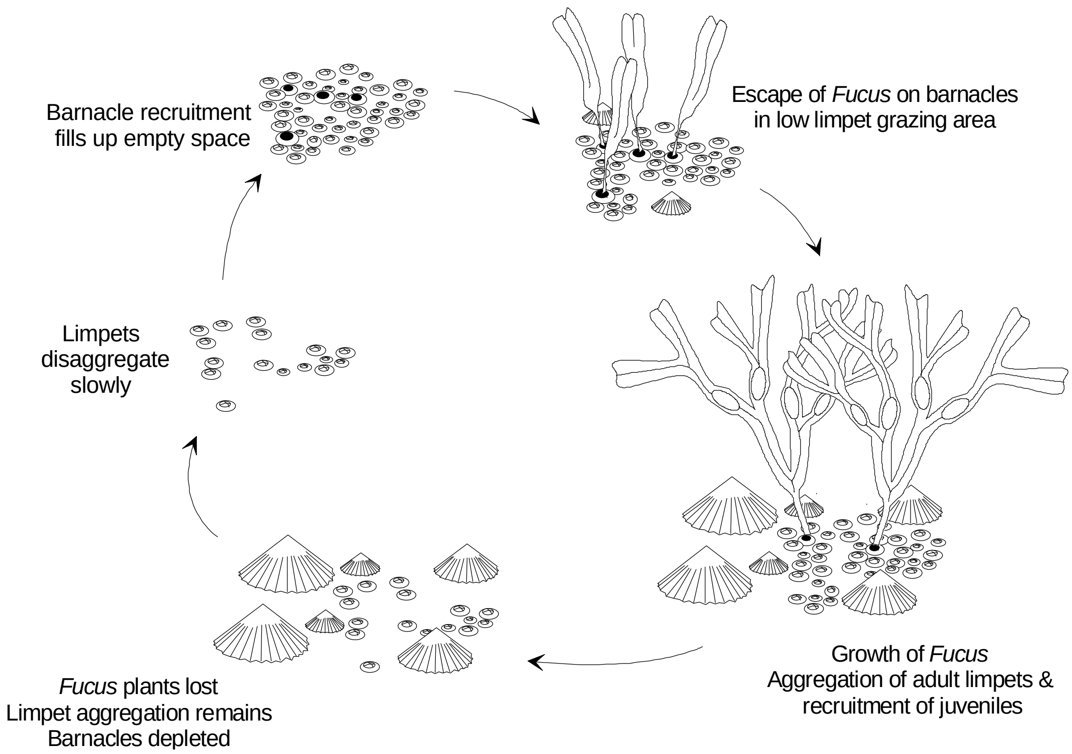

Figure 5. Pictorial representation of the sequence of events on a patchy moderately-exposed shore over several years**.**

D. MACROALGAL INFLUENCES

A major biological influence on community structure is the presence of algal canopies and shorter algal communities at mid and low shore levels. **Macroalgae provide** a variety of resources which are not available on bare rock. Most importantly, they increase the amount of **space** available for attachment, they provide **shelter** from wave action, desiccation and heat **and** they are an important **food** source.

The presence of algae can have positive effects on some species and negative effects on others, as illustrated by the interaction between *Fucus vesiculosus,* limpets and barnacles (Section III.C above). Algal canopies reduce light availability to understorey plants and can trap silt which smothers some organisms at the same time as providing an environment for burrowing species. Removal of high shore canopy forming species often leads to a proliferation of turf forming algae including some species which are usually more common as epiphytes (Hawkins and Harkin, 1985). Higher on the shore, such canopy species are damaged when *Ascophyllum* spp. are removed (Hawkins, 1979; Jenkins, 1995)

Bryozoans, hydroids and *Spirorbis* spp. grow on algal fronds at low shore levels. A more mobile fauna colonises higher shore algae. Epiphytic algae are also common on kelps and fucoids. These provide food for grazers and predators while the brown macroalgae also provide food for grazers such as *Littorina* obtusata and blue rayed limpets. Sediment stabilised by the canopy is further stabilised by the sand-binding red alga *Audouinella floridula* and colonised by infaunal species. The net result of algal canopies and turfs is usually an increase in species richness (see Williams and Seed, 1992) for review.

E. LARVAL SUPPLY

Many rocky shore species have a **planktonic dispersal phase**. These species produce propagules or larvae that spend their early life in the open sea and may eventually settle on shore some distance from where they originated. This strategy allows species to rapidly colonise new areas that become available and reduces the risk of extinction as long as there are some enclaves of adults producing planktonic juveniles. The supply of larvae and propagules in any year is dependent not only on the size of the reproducing population but also on numerous physical factors (Chapter II).

The level of larval supply and its fluctuations play a considerable role in structuring rocky shore communities and have been appreciated for a long time (Southward and Crisp, 1956, Lewis, 1964, Kendall *et al.*, 1985). Biological interactions, including intraspecific competition, are more intense in areas of high recruitment and recruitment fluctuations can cause instability (Gaines and Roughgarden, 1985; Menge *et al*., 1985; Menge and Olson, 1990; Menge, 1992; Gaines and Bertness, 1992). The continued coexistence of the barnacles *Semibalanus balanoides* and *Chthamalus* on the mid-shore in southwest England probably owes a great deal to recruitment variation. Sometimes space is undersaturated due to low recruitment (Burrows, 1988; Southward, 1991). *Chthamalus* produce abundant larvae in warm years while *Semibalanus* performs better in cool years. The favoured species will have a high settlement rate and increase its abundance. Fluctuations in annual temperatures prevent either species from excluding the other. This contrasts with the situation at Millport, where *Semibalanus* larvae are usually abundant and the species excludes *Chthamalus* from the mid-shore (Connell, 1961a,b). Dense settlements of barnacles can lead to severe intraspecific competition. Individuals increase in height but are unable to grow laterally. This can lead to feeble attachment and the dislodgement of whole sheets of fragile individuals (Barnes and Powell, 1950). Dense settlements of prey species can ensure that at least some juveniles escape predation (Sebens and Lewis, 1985).

F. ENERGETICS AND INTERACTIONS WITH OTHER ECOSYSTEMS

One of the defining characteristics of a rocky shore is that it exists at the interface between marine and terrestrial ecosystems. Consequently, there are strong interactions between the communities of the shore, land and sea. Coasts, including rocky shores, are highly productive (Hawkins *et al*. 1992). Shallow water allows the penetration of light which promotes primary production in macroalgae and the microbial film which coats the rock. Rocky shores also benefit from primary production in phytoplankton which are washed over the shore with each tide. The sea also brings detritus in a range of particle sizes. Whole kelp plants and other algae washed up on the shore are eaten by littorinids, crustaceans and limpets. Banks of mixed seaweeds can accumulate on the strandline, where they support populations of invertebrate scavengers of both terrestrial and marine origin. Small detrital fragments and phytoplankton are consumed by filter feeders such as barnacles and mussels. Particulate organic matter in this form is the main route of material flowing up the detrital food chain.

1. Fate of primary production by macroalgae

Macroalgae exude considerable amounts of dissolved organic carbon which are taken up readily by bacteria and may even be taken up directly by some larger invertebrates. Only about 10% of the primary production is directly cropped by herbivores (Raffaelli & Hawkins, 1996). On exposed shores, grazers feed mainly on the microbial film. Dissolved organic carbon, algal fragments and microbial film organisms are continually removed by the sea. This may enter the food chain of local, subtidal ecosystems, or be exported further offshore. Rocky shores also make a contribution to the food of many marine species through the production of planktonic larvae and propagules which supply essential biochemicals to pelagic food chains.

2. Rocky shores as nursery grounds

The rocky subtidal is an important nursery area for many commercially important species of fish including herring and gadoids. These can migrate into the intertidal zone at high tide but there is little evidence of any dependence on littoral communities. However, fish and crustaceans, migrating into the intertidal to feed as the tide rises, are important predators of rocky shore species. Corkwing wrasse, which are important to the aquaculture industry as a cleaner species rely heavily on the intertidal. Juveniles are commonly found in rockpools.

3. Rocky shores as feeding areas for birds and mammals

Shore birds also feed on the rocky shore (Feare and Summers, 1985). The invertebrates attracted to seaweed on the strandline are a particularly important food source. Rich pickings can also be had under macroalgae canopies. Otters often use rocky shores and will feed on animals such as shore crabs which, in turn, feed on rocky shore species. Opportunistic mammalian species such as rats, rabbits and even sheep will forage on available rocky shores.

G. KEY SPECIES

Rocky shore communities are structured by interactions, such as competition for space, among the key species. The effects of competition are often influenced by other species. Grazing by limpets, for example, prevents fucoid species from establishing on more exposed shores (Jones, 1948; Southward and Southward, 1978; Hawkins and Hartnoll, 1983). The influence of the grazers therefore has a dramatic effect on the structure of the whole community on more exposed shores. Similarly canopy interactions shape sheltered shores and the sublittoral fringe,

Rocky shores are occupied by many species, some of which have a relatively minor effect on the abundance of others. Others directly influence the abundance of other species, either through competition, predation or grazing. As the *Fucus* - barnacle mosaic example (p29) shows, interactions between two species can have knock on effects to other neighbouring species. In Chapter VI we advocate a monitoring strategy based on abundance estimates for a limited number of important species. This should include indicator species for specific impacts but should be based mainly on those species which characterise and structure rocky shore communities. Foremost among these are **those which occupy** most of the available **space** including barnacles, mussels, fucoids and kelps. Abundant **mobile animals** such as littorinids should also be included. Of particular importance are those which exert an influence on the rest of the community through affecting the outcome of competitive interactions between other important species. **Limpets** are the best example on UK shores. There is little evidence that dogwhelks play a substantial role in structuring communities, though they are abundant **predators** on many rocky shores. The implications for the community of predation by species which migrate onto the shore to feed when the tide is in are not fully understood. Many rocky shore communities are also affected by the actions of animals which are not seen at low tide; for example, seasonal invasions of the lower shore by predators such as *Asterias rubens* and *Echinus esculantus*. The outcome of these biological interactions result in the observed dynamics and distribution patterns. Major **space occupying species provide substantial secondary habitat for smaller species**. This is particularly the case for canopy forming algae (Seed and Williams, 1992) and mussels (Seed, 1995).

H. BIODIVERSITY

1. Biodiversity definition and application on rocky shores

Biodiversity is a general term covering all aspects of biological diversity, from genetic variability within species to species richness: a measure of number of species compared with the number of individuals in a community and ecosystem complexity. As described above, rocky shore ecosystems are often characterised by strong biological interactions, with the presence or absence of some species having indirect repercussions on others. An important contribution to biodiversity at the level of the physical habitat is the wide range of biotopes found on rocky shores resulting from environmental gradients and structural complexity of the shore. Each species reaches the peak of its competitive ability at a given intersection of the habitat gradients and yet its distribution is ultimately influenced by interactions with other species. **Rocky shores encompass a vast range of habitat and community characteristics over a very narrow spatial scale.**

2. Trends in biodiversity

The **diversity** of species on rocky shores **increases towards the low shore** where conditions are more benign. A limited number of species are able to survive on **extremely exposed shores**, particularly those consisting mainly of steep, smooth rock. As a result these shores **have** a **low biodiversity**. Protected microhabitats on exposed shores, such as algal turfs or deep crevices, can however support a surprising variety of species (Raffaelli and Hawkins, 1996). The presence of zonation patterns indicates that large proportions of available space are dominated by a few species. However, these species often provide a microhabitat for others. Older barnacle shells are pitted by boring blue-green Cyanobacteria and the pits shells provide shelter for large numbers of diatoms (Thompson *et al.*, 1996). **Algal canopies**, and kelp **holdfasts** especially, support a variety of epiphytic species as described above and **mussel beds** provide a refuge and habitat for a great number of species including representatives from most of the main invertebrate phyla (Seed, 1996). At higher shore levels, tardigrades live beneath lichen crusts. These examples illustrate the importance of biological **microhabitat provision** on rocky shore diversity. **Physical complexity** is also important with crevices, rock pools and the underside of boulders all harbouring **diverse species** assemblages, including species which are restricted to these microhabitats.

In general, species diversity and numbers increase with habitat complexity (Kostylev *et al.*, 1996). The abundance of any species is determined by the resources available and its ability to compete for them. Therefore, species diversity will be greatest in those shores which are rich in varied microhabitats. Mussel beds are recognised as an important source of biodiversity (Seed, 1996; Holt *et al.* 1998). The presence of biogenic microhabitats can have a negative effect of the number of individuals in a given area. For example, more species but fewer individuals are found between *Fucus* clumps than on barnacle encrusted rock on UK shores (Thompson *et al.*, 1996). This is entirely due to the negative influence of *Fucus* on barnacle numbers.

I. KEY POINTS

- While physical factors clearly influence the distribution and abundance of species on rocky shores it is the interaction between physical and biological factors that is responsible for much of the structure and dynamics of rocky shore communities. while physical factors directly influence the upper limits of the distribution of many species.
- Biological factors (primarily competition and predation) sometimes set upper limits but mostly act on lower limits.
- Rocky shore communities are often highly variable in time, due to the combined effects of physical disturbance, competition, grazing, predation and variation in recruitment.
- Many communities are dominated by a small number of species which occupy the majority of available space.
- The structure of communities may also be strongly influenced by the presence of a few important consumers which control the numbers of some of the species competing for space. These key species can be used to determine the general condition of the communities they characterise.
- Rocky shore communities are productive and an important source of food and nutrients for members of neighbouring terrestrial and marine ecosystems.
- Rocky shores can often be highly complex ecosystems, due to high levels of habitat variation over short distances. Homogeneous surfaces are often dominated by a few abundant species. Most of these species, particularly algae and mussels provide microhabitats for other, less common species. Cryptic microhabitats are characterised by communities quite different from those seen on open rock and are an important source of biodiversity.
- Species diversity and biomass generally increases towards the low shore.

IV.
SENSITIVITY TO NATURAL EVENTS

A. INTRODUCTION

Environmental change is a key feature of the rocky shore habitat through tides waves and exposure to the air. Breaking waves impose extreme mechanical forces on rocky-shore animals and plants (see Denny, 1995 for review). More than any fully marine ecosystem, therefore, the littoral zone endures constantly changing physical conditions. The extent of these changes is a major factor shaping the community of any shore. Rocky shore species have adaptations which allow them to survive the fluctuations they experience on a daily basis. However, intense levels of biological interaction can occur on rocky shores. In some cases, these interactions lead to instability in the community. In other cases, stable communities exist, structured by grazing, predation and competition. Even in stable communities, the abundance of many species can fluctuate significantly with the seasons. **Shifts in physical conditions can restructure these communities by altering the relative abilities of different species to compete for space.**

Many of the dominant species on rocky shores are adept at colonising empty space. Primary producers and filter or suspension feeders with motile larval phases can rapidly colonise bare rock after a disturbance. The process of recovery can begin rapidly and succession on rocky shores occurs over relatively short time scales, in the order of less than 5 to 10 years. The exception is very sheltered, shores dominated by *Ascophyllum* spp., where recovery may take tens of years. Frequent physical and biological disturbance from natural sources means that the abundance of all species shows some degree of fluctuation over time, although very sheltered shores can be quite stable.

Succession and community changes resulting from biological interactions are discussed in Chapter III. This chapter will concentrate on changes in shore communities due to physical factors and begins with a discussion of the relative stability of various rocky shore communities under natural conditions.

B. THE STABILITY OF SOME ROCKY SHORE COMMUNITIES UNDER NATURAL CONDITIONS

This review describes several causes of natural changes in rocky shore communities. All communities show some degree of temporal variability and many rocky shore communities show a good deal of natural fluctuations. The abundance of limpets, barnacles and *Fucus* plants may be relatively constant over a large area of shore. However, in a smaller area of that shore, an aggregation of limpets might be replaced by a patch of barnacles and then of *Fucus* plants over the course of a few years. Connell and Sousa (1983) suggest that communities should be thought of in terms of their persistence within stochastically defined bounds. In other words, how long will an assemblage of species coexist, given the natural variability in their populations and will they continue to coexist after a natural perturbation? Clearly these questions are scale dependent; the area of interest should be defined before they are asked.

Chapter I describes the MNCR biotope classification scheme which describes areas according to a mixture of community and habitat characteristics. This scheme allows a characterisation of the shore at any instant. Any single description of the status of a community, however, cannot account for the temporal and spatial variation characteristic of natural ecosystems. These characteristics must be recognised and accounted for if management and conservation of rocky shores is to be effective. Ultimately, a well designed monitoring programme will be the best way to understand the spatial and temporal dynamic features of any given shore community.

The MNCR biotope scheme is likely to be widely used in the conservation and management of marine SACs. Appendix 1 gives a qualitative assessment of the likely stability and persistence of the communities represented by the MNCR intertidal reef biotopes (full descriptions of each type are given in Connor et al., 1997). Interpretation of the results of single surveys couched in the terms of the biotope scheme must take account of the likely permanence (or transience) of each biotope. CAPITALS denote emphatic statements about the likely stability can be made.

C. EFFECTS OF PHYSICAL DISTURBANCE

1. Creation of new space for colonisation

Space is the major resource for which rocky shore species compete. Removal of space-occupying individuals provides room for new individuals to colonise. In contrast to predation and grazing (Chapter III), the removal of individuals by physical processes is not species selective. Sessile prey such as barnacles become increasingly unstable as they grow older and larger. The action of waves can dislodge mats of these animals. The action of waves can be more damaging when they carry hard materials which smash into or scour the shore. In heavily forested areas, such as Canada and the northern USA, water borne logs are the most common cause of disturbance. The force of a log smashing against the shore is sufficient to kill and dislodge most barnacle and mussel species (Shanks and Wright, 1986). Disturbance due to drift wood and other debris probably has a relatively minor effect on most UK bedrock shores. However, waves can also move rocks and stones (Shanks and Wright, 1986). When stones on boulder shores are turned over or crash into each other, the organisms on the affected side can be wiped out (Sousa, 1979). Connell (1961) reports significant mortality of barnacles due to water borne debris on a Clyde Sea shore during gales in 1955. Similar effects are caused when shores are scoured by sand or gravel in suspension.

2. The Intermediate Disturbance Hypothesis

Caswell’s (1978) intermediate disturbance hypothesis suggests that at low levels of disturbance, a few competitively superior species will dominate communities resulting in low levels of diversity. At intermediate disturbance levels, frequent removal of these species will provide space for others, resulting in high diversity. At very high levels of disturbance only a few very tolerant or opportunistic species will occur. This hypothesis has been tested in boulder fields where it seems to hold true (Sousa, 1979). Physical disturbance appears to play a role in structuring communities with limited disturbance promoting biodiversity.

3. Physical effects on individual performance - wave action

Rough seas can affect the extent of biological interactions on the shore. During periods of rough weather, dogwhelks are more likely to remain sheltered in crevices than to forage for prey on exposed rock surfaces (Burrows and Hughes, 1989). During prolonged periods of harsh weather they will shelter in crevices low on the shore. As conditions abate, for example in spring, the predators emerge as a front, depleting barnacle populations close to the crevice. High amplitude waves and heavy swells may also reduce predation in the littoral zone by mobile predators such as crabs and fish. The effects of predation intensity on rocky shore communities are discussed in Chapter III.

D. CLIMATE

Rocky shore communities are particularly susceptible to the effects of extremes in weather. Stormy weather can cause the disturbances described above but at the same time, heavy seas produce spray which reduces desiccation stress for high shore species. Wet weather reduces the salinity of rock pools. Cold weather can cause freezing stress and even ice scour at high latitudes. Calm weather reduces wave action, prolonging the period of emersion, which has been reported to increase the mortality of barnacle cyprids (Connell, 1961a,b). Warm, dry weather increases desiccation stress. It is unsurprising that the geographical range of many rocky shore species is determined by climatic conditions. Not only can unfavourable weather conditions cause mortality to susceptible species, they can also affect the outcome of competitive interactions between species. The competitive ability of a species will be limited by increases in a stress to which it is susceptible. The prevailing climate ultimately affects the sea temperature which is the major factor determining the breeding success and therefore the distribution of most marine organisms. Sea temperature and, therefore, the distribution of organisms can be indirectly affected by the climate of more distant areas, acting through ocean currents. Changes in temperature may also affect reproductive output directly. Southern species, such as the barnacle *Chthamalus stellatus*, may produce fewer offspring over a shorter breeding season if temperature drops (Burrows *et al.*, 1992).

1. Climatic regions, oceanographic processes and distributions of species

The UK straddles a major biogeographic boundary with many southern species reaching their limits in Ireland or southwest Britain (Lewis, 1964). At various points on the UK coastline, species associated with warm temperate regions reach the northern limits of their distributions and arctic and boreal species reach their southern limits. The exact distribution range of species is usually variable in response to changes in climate. This fact is well illustrated by the changes in rocky shore communities in southwest England recorded from 1950 to 1993 by workers at the Marine Biological Association (Southward *et al*., 1995). During this time, the annual average local sea temperature followed a rising trend until 1960, cooled from 1961, markedly so from 1970 and began to rise again after 1981. During periods of warming, warm water species increased in abundance and extended their range while cold-water species declined. The reverse was true during periods of cooling.

a) Case study: Warm and Cold water Barnacles.

Changes in the relative abundance of the cold-water barnacle *Semibalanus balanoides* and its warm-water counterparts *Chthamalus stellatus* and *montagui* can be seen with both location and time. These changes show strong links with climatic conditions (Southward, 1991, Southward *et al*., 1995) and larval supply (Kendall *et al*., 1985).

On the shores of Great Cumbrae in the Clyde Sea, *C. montagui* is restricted to high shore levels (Connell, 1961a,b; 1972) with *S. balanoides* dominating the mid and low shore. Connell (1961a,b) showed that competition with the faster growing *S. balanoides* restricted *C. montagui* to upper shore levels/ In the Southwest of England, *Chthamalus* spp. and *S. balanoides* coexist on the mid shore, though the exact balance of numbers varies with climate (Southward *et al.*, 1995). In the 1950s, *Chthamalus* spp. dominated on south-western shores. A cold winter in 1962/3 led to a rapid increase in *S. balanoides* numbers and this species remained abundant during the period of cooling in the 1960s and 1970s. *Chthamalus* spp. numbers have increased since the late 1980s but have not yet reached the levels seen in the 1950s. The ratio of *Chthamalus* spp. to all barnacles shows a particularly strong relationship with climate. Bay of Biscay sea surface temperatures provide a good predictor of this index with a time lag of two years (Southward *et al.*, 1995). This time-lag approximates to the average interval between the beginning of reproduction in successive generations of *Chthamalus* spp. The relationship with offshore sea temperatures suggests the strong influence of the ocean on distribution patterns in the English Channel.

The interaction between *Chthamalus* spp. and *Semibalanus balanoides* is greatly affected by physical factors. Temperature appears to be among the most important of these, affecting fecundity, settlement, recruitment and the outcome of direct competition for space. Low temperatures reduce the breeding period, settlement and recruitment of *Chthamalus* spp. (Kendall *et al.,* 1985). Survival and recruitment in *Semibalanus* are adversely affected by high temperatures late in the year (Kendall *et al.*, 1985). The coexistence of these barnacles in the Southwest of England owes much to the availability of space on the shore due to occasional years of low recruitment (Burrows, 1988; Southward, 1991). The relative reproductive output of *S. balanoides* and *Chthamalus* spp. varies with temperature. Since both have refuge populations producing a supply of larvae, both can take advantage when conditions swing in their favour. In areas dominated by *S. balanoides*, the presence of *Chthamalus* spp. on the high shore may be explained by increased mortality of the dominant species due to desiccation or heat stress. Wethey (1984), working in New England, showed that *S. balanoides* were able to overgrow, crush or undercut *Chthamalus* spp. on the high shore, thus out-competing them for space, when provided with shade.

b) Limpets

Patella vulgata is usually the most abundant limpet on UK shores. Its range extends from the Arctic to the southern tip of Portugal. *P. depressa* is a more southern, warm water species. Its range extends from the North Wales coast to North Africa. In the late 1950s, towards the end of a period of warming which began at least as far back as 1920, *P. depressa* was well represented in the limpet fauna of Southwest England. Its numbers declined throughout the 1960s and 1970s and began to increase again in the mid 1980s. During the 1980s, a rapid increase in *P. depressa* numbers was recorded on the North Cornwall coast coupled with a decline in *P. vulgata*. Limpet grazing has important consequences for the community, leading, for example, to the dynamic *Fucus*-barnacle mosaics observed on moderately exposed shores (Hartnoll and Hawkins, 1985, Hawkins and Hartnoll, 1983, see Section III.C, p28). Absolute changes in limpet numbers can therefore have community wide effects. On the west coast of England, however, the absolute number of limpets stays more or less the same but the species balance changes.

c) Other species

Long-term changes in temperature have apparently led to changes in the southern limit of the range of the cold water kelp *Alaria esculenta* (Widdowson, 1970). Similarly warm water species such as the topshell *Monodonta lineata* and the barnacle *Balanus perforatus* were commoner and more widespread on Southwest English coasts in the 1950s than in the late 1960s. As with the limpets described above, several complementary pairs of rocky shore species exist. Each pair consists of a northern and a southern species. Where their ranges overlap, changes in the ratio of the two species are seen, mediated by some climatic factor. A well studied pair is the northern barnacle species *Semibalanus balanoides* and its southern counterparts *Chthamalus stellatus* and *Chthamalus montagui* (See Section IV.C, p37).

2. Climatic effects on reproduction and survival

The climate affects every stage in the life history of rocky shore species. Duration of the breeding season can be temperature dependent, as in *Chthamalus stellatus* and *Chthamalus montagui* producing fewer broods near their northern limits (Burrows et al., 1992). The survival and settlement of larvae is affected by sea temperature and hydrographic transport processes (see next section). The level of stress experienced by settled individuals at each shore level is tightly linked to climatic conditions. Thus, changes in climate affect the reproductive fitness and, therefore, distribution and abundance of individual species. Changes in the numbers of important species (see Section III.G) are likely to have profound effects on community structure. Since there is well documented evidence of changes in the distribution and abundance of rocky shore species in response to climate change (Southward *et al*., 1995; Hawkins *et al*., 1993) and rocky shore communities are easily surveyed, rocky shores may provide a means for monitoring long term climatic change (see Chapter VI, p51 *et seq.*).

3. Seasonal changes in communities

The composition of the shore community also changes with the seasons. For example, increasing daylength in the spring encourages the proliferation of ephemeral algae such as green *Enteromorpha* and *Ulva* and brown *Pilayella* and diatoms. Seasonal fluctuations in these algae are especially pronounced high on the shore. The barnacle population is depleted by the foraging activity of dogwhelks from spring to early winter. The population is replenished by settlements of *S. balanoides* in the spring and *Chthamalus* in the summer and autumn. Such seasonal changes are common to many communities and can exist in the absence of long term changes.

E. LARVAL SUPPLY

The importance of larval supply to the community ecology of rocky shores is described in Chapter III. Production of larvae depends on the size of the reproducing population, the rate at which offspring are produced, and the length of the reproductive season. Rate of reproduction may depend on food supply, in turn influenced by water movement, light availability, temperature and competition. Recruitment in species with widely-dispersed larval stages may be more sensitive to variation in those environmental factors affecting conditions for successful development and transport to appropriate habitats. Survival of larvae will be affected by water temperature and food supply. The inshore transport of larvae can depend on water movement which, in turn, is influenced by wind direction.

Community structure and dynamics are strongly influenced by larval supply. Much of the natural variation around the mean abundance in stable communities might be due to variations in larval supply. However, more unstable systems can easily be pushed in a particular direction by a series of chance events. For example, in a *Fucus*-barnacle mosaic (Section III.C, p28), a low recruitment of limpets or a high recruitment of barnacles might lead to reduced limpet grazing and, therefore, more *Fucus* escapes resulting in a *Fucus*-dominated community. Variable recruitment can generate instability. If a dominant competitor has a low recruitment, an inferior competitor might be able to invade the community, exploiting new space that becomes available.

F. KEY POINTS

- MNCR biotopes are associated with biological communities with particular characteristics of stability and persistence. An interpretation of these biotopes is given in Appendix I of this review for management and conservation of rocky shores in a dynamical context. Monitoring programmes may be necessary for a more thorough understanding of the spatial and temporal dynamic features of shore communities.

- Shifts in physical conditions can restructure communities on rocky shores by altering the relative abilities of different species to compete for space.

- Physical disturbance affects communities through the provision of new space for colonisation. Wave-borne debris, including log, rocks, stones, gravel or sand, can be most damaging.

- The Intermediate Disturbance Hypothesis may apply to rocky shore communities. At low levels of disturbance, a few species dominate the community resulting in low diversity; at intermediate levels, frequent removal of these species will provide space for others, resulting in high diversity. At high levels of disturbance only a few tolerant or opportunistic species will occur. Physical disturbance appears to play a role in structuring communities with limited disturbance promoting biodiversity.

- Adverse physical conditions may impair the performance of species which may otherwise structure shore communities. Wave action reduces predation by dogwhelks.

- Climatic changes can affect the relative abundance and range of sensitive species. Changes in the abundance of the cold-water barnacle *Semibalanus balanoides* and its warm-water counterparts *Chthamalus stellatus* and *montagui* reflect changes in water temperature over four decades. Long-term changes in temperature have led to changes in the southern limit of the cold water kelp *Alaria esculenta.*

- The composition of the shore community changes with the seasons. Increasing day length in the spring encourages ephemeral algae and diatoms. Seasonal fluctuations in these algae are especially pronounced high on the shore.

- Community structure and dynamics are strongly influenced by larval supply. Much of the natural variation around the mean abundance in stable communities is due to stochastic variation in larval supply of key species.

V. SENSITIVITY TO HUMAN ACTIVITIES

A. INTRODUCTION

An important theme of this report is that the community structure of some intertidal reef biotopes is highly variable in space and time. Against this background of natural variation, human impacts may not be detectable without detailed and, often, long term investigation (Stewart-Oaten et al., 1986, Underwood, 1991). Nor should observed changes be automatically attributed to anthropogenic disturbance. However, because of the dynamic nature of rocky shore communities, impacts on one species can have community-wide influences.

The purpose of this chapter is to review current understanding of anthropogenic impacts on rocky shore community structure and dynamics and the ability to distinguish these from natural changes. Natural physical disturbance is a common and often important factor affecting the structure and dynamics of rocky shore communities. Anthropogenic disturbances will be particularly damaging when they are sustained (chronic) or of high intensity (acute). Intertidal and littoral ecosystems are exposed to human impact more frequently than any other marine system (Schramm, 1991). Rocky shore communities and species are sensitive to both acute impacts, such as oil spills, and chronic impacts, such as those from TBT-based paints and recreational activities. The responses of communities to these impacts are often well studied and documented, enabling conservation strategies to be suggested (see Chapter VIII). Other anthropogenic impacts on rocky shore communities include the introduction of non-native species and the potentially positive effect of increased habitat provision through building of sea defences.

While this chapter contains a discussion of some of the most notable human impacts on rocky shore communities, it is not intended as an exhaustive guide. Any human activity which alters the physical, chemical or biological nature of the coastal environment should be regarded as having the potential to impact rocky shore communities. A more comprehensive account of the sensitivity of marine communities to human activities is given by Holt *et al.* (1995).

B. CHRONIC FACTORS

Chronic impacts are those which have a long duration, on a scale of years. The effects of these impacts are often subtle but can, nevertheless, have severe consequences for biological communities. Any long term climatic change which results from human activity could cause chronic impacts on rocky shore communities as discussed in Chapter IV. Low intensity pollution and physical disturbance are the main sources of chronic impact on rocky shores. Shorelines are especially susceptible to the effects of chronic pollution since discharges often occur close to the shore or into rivers and the shallow water limits the potential for dilution of pollutants.

1. Sewage

The most severe effects of sewage effluent discharge occur in semi-enclosed areas such as estuaries and sheltered bays. Effects on high-energy rocky shores are negligible, while effects on low- to medium-energy rocky shores can be more pronounced. Water movement limits the build up of particulates and prevents eutrophication. Thus, the ecological effects of large sewage outfalls may stretch to a few hundred metres while the effects of smaller discharges are usually confined to within about 10m of the pipe (Raffaelli and Hawkins, 1996). Such discharges can, for example, encourage the growth of ephemeral green algae in the affected area. Sewage outfalls can introduce plastics and other solids to the marine environment. These can disfigure large areas of shore, though their effects are mainly aesthetic. From 1998, the U.K. government will be enacting E.U. law to progressively reduce sewage discharge into the sea.

2. Biocides: Tributyltin

The **toxic effects of tributyltin** (TBT) on molluscs, especially the dogwhelk ***Nucella lapillus***, are well documented (Bryan *et al*., 1986, 1987). TBT, an organotin, was extensively used in antifouling paints specifically to kill marine fouling organisms. Unsurprisingly, it therefore had an ecological impact. Many rocky shore communities have been and continue to be impacted by the sublethal effects of TBT and its breakdown products which can occur at concentrations of less than 1ng Sn l^{-1} (Bryan *et al.,* 1986).TBT is lipophilic in nature. Consequently it becomes concentrated in the water surface microlayer which is rich in lipids. It is this microlayer which washes over rocky shore organisms each time the tide rises and falls. Effects on settling larvae that also accumulate in the surface layer are less well known. Given the original purpose of TBT as antifouling agent such effects are likely to be considerable.

Many shallow coastal waters escape the pollution associated with busy harbours and industrialisation. However, the expansion of **recreational boating exposed previously clean areas to the effects of TBT**. The impact was greatest in areas with heavy boat traffic and close to marinas, where boat moorings and maintenance activities were concentrated.

Very low concentrations of TBT can lead to the condition known as imposex in dogwhelks. Imposex is the development of male sexual characteristics, including a penis and vas deferens in females. At concentrations of around 2-3ng Sn l-1, sterilisation of females can occur as the vas deferens blocks the genital pore, preventing egg capsules from being released. **At higher concentrations, virtually all females are sterile** (Bryan *et al.*, 1987). This results in a change in the structure of dogwhelk populations. Since dogwhelks have no larval dispersal phase, local populations are sustained by their own fecundity. Therefore these populations become less abundant and increasingly dominated by adults as exposure to TBT increases.

Dogwhelks are an important predator on rocky shores and their decline might be expected to have profound effects on the rest of the community. Dogwhelks are less abundant on sheltered shores where their prey are less common (Spence *et al.*, 1990). The main sources of TBT release (fish farms, harbours and marinas before legislation) are usually in sheltered sites. Thus the gradient of reduced abundance due to impact runs in the same direction as the gradient of reduced abundance due to habitat features. This fact might potentially mask subtle effects of TBT on dogwhelk populations. Dogwhelks are an important predator on rocky shores and might determine the timing of the switch from barnacle to algal domination in areas of these shore (Section III.C). TBT also affects mussels, an important space occupying species on rocky shores and may therefore have important effects on community structure. Evidence for community-wide effects is, however, limited (Hawkins et al., 1994)

The use of TBT paints on small boats was banned in the late 1980s. However, recovery has been impeded because dogwhelks are slow to recolonise areas which have suffered population decline. Furthermore, it is now recognised that TBT originating from larger vessels also has detrimental effects (Davies and Bailey, 1991).

3. Biocides: Ivermectin

Ivermectin is a pesticide which is used to control sea lice on farmed salmon. It is currently licensed to 15 salmon farms in Western Scotland. Ivermectin targets the neuromuscular system of invertebrates and is acutely toxic to lugworms (Thain *et al*., 1998), reducing activity at concentrations as low as 6ppb and causing death at 23ppb. Ivermectin can reduce the abundance of infaunal polychaetes (Black *et al.*,1997) and is also lethal to starfish and shrimps (‘No Free Lunch’, *New Scientist*, 7 February 1998). The effects of ivermectin on rocky shore communities remain to be studied. However, since the pesticide is toxic to a wide taxonomic range of invertebrates, its wider use could potentially impact rocky shore communities, either by reducing the competitive abilities of susceptible animals or by causing death.

C. HARVESTING

Several rocky shore species are exploited by man in the UK. The main commercial species are seaweeds (knotted wrack, *Ascophyllum nodosum* and kelps, *Laminaria* spp), winkles (*Littorina littorea*), mussels (*Mytilus edulis*) and edible crabs (*Cancer pagurus*). Knotted wrack is traditionally harvested from the sheltered shores of sea lochs in the Western Isles. It is used in the industrial production of alginates. Kelp plants are collected from the strand line for use as fertilisers and animal feed. Winkles, mussels and crabs are harvested primarily for food. Invertebrates are also collected for use as bait by sport fishermen. Any species of crab which is about to moult (‘peelers’) or has recently moulted (‘soft shells’) are popular. Mussels are also used in some areas (Fowler, 1992).

The removal of any species can have unforeseen effects on other members of the community (Wells and Alcala, 1987). These effects are expected to be greatest when key species are removed. Seaweeds are responsible for much of the primary production on rocky shores and are important providers of microhabitat for other species. Winkles are an important grazer and mussels are a particularly important space occupying species. The recovery of any population will depend on the degree of exploitation. Mechanical harvesting of kelps like *Laminaria hyperborea* by dredging removes the whole plant. Clumps of *Ascophyllum* spp., on the other hand, can regrow after careful hand cutting. Such careful harvesting is necessary since *Ascophyllum* spp. is slow to recruit after it has been completely removed. A review of the impact of kelp harvesting is provided by Wilkinson (1995). Dredging trials for *Laminaria hyperborea* for alginate production were successfully carried out in Scotland in recent years but have not continuing.

Historically, large quantities of mussels have been harvested from UK shores. Collecting now occurs at much lower levels (McKay and Fowler, 1997a). Thus the impact is probably limited to low level disturbance. Substantial winkle collecting still occurs. This is a largely unrecorded ‘black economy’ activity. Official figures suggest that the annual harvest for Scotland amounts to approximately 2000 tonnes. Figures based on buyers’ estimates suggest that the annual harvest could be over 4,000 tonnes (McKay and Fowler, 1997b). Declines have been reported in the winkle population in areas where it is heavily exploited. Elsewhere in Europe the impact of exploitation of many rocky-shore species is high. Sea urchins are extensively collected in France, Spain and Italy, while stalked barnacles (*Pollicipes* species) are gathered in Spain and Portugal. Even limpets are harvested in Southern Portugal, the Azores, Madeira and the Canaries (Raffaelli and Hawkins, 1996). Historically, they were once heavily collected in the British Isles, as evidenced by various shell middens.

An additional problem associated with harvesting and bait collection is disturbance. Rocks turned over during the collection of peeler crabs might not be replaced and the removal of mussels can destabilise neighbouring animals. The impact of any harvesting or collecting activity will vary depending on the species exploited, how it is done and to what extent. It is strongly recommended that any such activities occurring in or close to marine conservation sites should be closely monitored.

D. RECREATIONAL IMPACT

The recreational use of the shore can have adverse effects on the biological community. The effect of people **simply walking on the shore can be damaging**. This is particularly apparent when the topography of the shore causes people to follow a limited number of routes, leading to the appearance of paths characterised by **reduced cover of fauna and flora** (Fletcher, 1997). While such pathways represent a limited area of the shore, they are nevertheless unsightly. It is also apparent that the lighter trampling pressure experienced elsewhere on popular shores can cause changes in community structure. For example, even very light trampling on shores in the Northeast of England was sufficient to reduce the abundance of fucoids (Fletcher and Frid, 1996) which, in turn reduced the microhabitat available for epiphytic species. Light trampling pressure has also been shown to damage and remove barnacles (Brosnan and Crumrine, 1994). Trampling pressure results in an increase in the area of bare rock on the shore. This might be temporarily colonised by opportunistic species such as *Enteromorpha*. However, complete recovery cannot occur until the pressure is reduced.

In Chapter VII we argue that rocky shores have conservation value as a public amenity while in Chapter V we identify visitor pressure as a threat to shore communities. Clearly, this is an area of potential difficulty for the management of rocky shores within SACs. Pragmatic management policies should simultaneously protect rocky shores from recreational impacts and allow some degree of public access. Existing evidence suggests that a combination of public education and limited restrictions on access can minimise recreational impacts on rocky shores. Both of these measures require a considerable investment of resources. **Site by site assessments of recreational impact and management may therefore prove worthwhile**. Important factors for consideration are listed below.

- **The nature and extent of public use of the shore.** Higher numbers of visitors result in greater disturbance. Even light use can alter the community (Fletcher and Frid, 1996). Some areas of a shore may be heavily used while others are not. Recreational disturbances usually have a highly uneven distribution.

- **The vulnerability of the community.** Relatively few studies have considered the effect of recreational impact on shore communities. It is likely that the effect is heavily dependent on both the structure of the natural community and the degree of disturbance. A monitoring programme conducted in tandem with a restriction of access to certain areas of the shore will give an indication of the local vulnerability to recreational impacts.

- **The effectiveness of management measures**. Assessment of the recreational impact on rocky shores may identify the need for management measures. Careful monitoring should be conducted to establish the effectiveness of any measures that are implemented.

The assessment of the sensitivity of rocky shores to recreational impacts and the development of management policies for these shores should be a priority area of research within affected SACs. A coordinated research effort between SACs could lead to significant advances in the understanding and management of recreational impacts.

E. ACUTE FACTORS

The highest profile of all potential impacts on rocky shores is achieved by those short-term 'environmental disasters' with highly visible and media-friendly effects. Such factors may not necessarily be those most important in the long term but where impacts are dramatic, shores may take years to recover.

1. Red Tides:

Red tides are blooms of toxic dinoflagellates and other algae which can cause the widespread mortality of marine and littoral animals. Although red tides occur naturally, there is increasing evidence that they can also result from human activities. Eutrophication of coastal waters may have caused the severe blooms of *Gyrodinium aureolum*, *Chrysochromulina polyepis* and *Craetium* spp. which devastated North Sea shores in 1988 (Smayda, 1989, 1990; Lindahl, 1993). The main rocky shore animals affected by these events were barnacles, dogwhelks, mussels and limpets which, as space occupiers, grazers and predators, have a strong effect on the community ecology (e.g. Southgate *et al.*, 1984).

2. Oil Spills:

In recent years, British shores have been affected by two major oil spills. The *Braer* spilled 85,000 tons of oil near Shetland in 1995. The *Sea Empress* ran aground off South Wales in February 1996, releasing 72,000 tons of oil which had disastrous effects on ecosystems along more than 100km of coastline. A more severe impact was caused by the *Torrey Canyon* oil spill in March 1967. Of the 119,000 tons of Kuwait crude on board, 100,000 tons were spilt and 40,000 tons came ashore. 14,000 tons, borne on the highest spring tides for half a century, were stranded on the Cornish coastline and 10,000 tons of dispersant were used in the clean-up operation. The effects of this dispersant on marine life were little understood at the time. However, it later became apparent that the effects of the dispersant were more severe than those of the oil itself. The *Torrey Canyon* oil spill provides an excellent case study of the effects of acute pollution on the rocky littoral thanks to the long term observations on affected shores which are reported in Southward and Southward (1978), Hawkins *et al.* (1983) and Hawkins and Southward (1992), and summarised in Raffaelli and Hawkins (1996).

a) Impact and Recovery from the *Torrey Canyon* spill

The first-generation dispersants available in 1967 proved highly toxic to marine life. Subsequent laboratory studies showed that the concentration required to kill 50% of intertidal organisms in 24 hours of exposure was between 5 and 100 ppm, with limpets in the genus *Patella* being highly susceptible. These lethal concentrations were much lower than those needed to disperse the oil, and consequently all animals and many algae were killed in areas of the shore close to dispersant spraying.

The effects on rocky shores of the removal of much of the biota were profound and long-lasting. The loss of *Patella* had a special significance in this respect, since this grazer is a key species in the north-east Atlantic, responsible for structuring midshore communities on moderately exposed and exposed rocky shores.

Table 3. The time course of recolonization of rocky shores in Cornwall, expressed in years from the date of the *Torrey Canyon* disaster, March 1967 (extracted from Hawkins and Southward, 1992).

	Lizard Point exposed	Porthleven (w. of harbour)	Sennen Cove exposed	Cape Cornwall	Trevone sheltered MTL reefs
Relative exposure to waves	+ + +	+ +	+ + +	+ + +	+
Amount of oil stranded	+	+ + +	+ +	+ +	+ +
Dispersant treatment	+	+ + +	+ +	+ +	+ + +
Persistence oil/oil-dispersant mix	< 1	< 1	< 1	< 1	< 1
Enteromorpha maximum	1	1	0-1	1	1
Maximum *Fucus* cover	2-3	1-3	1-3	1-2	1-3
Minimum of barnacles	2	3	3	3	2-6
Maximum numbers of *Patella*	?	5	?	3	5
Fucus vesiculosus starts to decline	4	4	4	3	4
Fucus vesiculosus all gone	5	6-7	5	6	8
Increase in barnacles	4	6	4	4	7
Numbers of *Patella* reduced	?	8	6-7	7	N.A.
Normal richness of species regained	5	> 10	9	8-9	> 9-10

Patterns of Recolonization: Table 3 (above), based on Southward and Southward (1978), summarizes information on the patterns of recolonization of various rocky shores between 1967 and 1977. The similarity of the overall pattern allows a generalized account of the course of recolonization on the midshore region. Following the death of grazing animals, a dense flush of ephemeral green algae (*Enteromorpha, Blidingia, Ulva*) appeared which lasted up to one year. After six months or so, large brown fucoid algae (mainly *Fucus vesiculosus* and *F. serratus*) began to colonize the shores. Very few animals were present under these dense growths of algae. Any surviving barnacles were overgrown and eventually died, whilst the dense canopy prevented subsequent recruitment of barnacles by the sweeping action of the *Fucus* fronds and larval barrier effects. This was probably reinforced by the dense population of the predatory dogwhelk *Nucella* which built up under the canopy so that barnacles declined to a minimum on most shores between 1969 and 1971.

Reappearance of grazers: The limpet *Patella vulgata* first recolonized the shores during the early winter of 1967-8 and survived well in the damp conditions under the extensive *Fucus* canopy, preventing subsequent recruitment of *Fucus* by their grazing activities. As the plants aged, grazing of the holdfasts reduced *Fucus* further and between 1971 and 1975 the shore became very bare with even fewer algae than before the spill.

With the disappearance of *Fucus*, the abnormally dense population of limpets abandoned their normal homing habit and migrated in fronts across the shore. Barnacle numbers increased on all shores once the fucoids declined. Following the bare period between 1974 and 1978, the shore went through a phase of increased *Fucus* cover, although overall cover never exceeded 40%. Limpet density increased with some fluctuations from 1975 before dropping in the early 1980s and then rising again, probably reflecting normal levels of spatial and temporal variation typical of limpet populations. During the period of dominance by the initial colonizing cohorts recruitment of limpets was low (e.g., 1969 - 1972) - presumably due to intense inter-age-class competition. Subsequently, recruitment improved, and after 1988 the population generally had 60-70% juvenile limpets under the length of 15mm.

Recovery of barnacle populations: After the initial decline following the spill, the barnacle population slowly built up at all shore levels. At a shore level equivalent to high water of neap tides, all counts from 1979 onwards were within one standard deviation of the pre-spill mean, although only one value (in 1990) exceeded the mean. At mid-tide level, a similarly irregular pattern was observed, with exceptionally high counts just after the bare phase in 1976. Lower on the shore, there was much greater fluctuation which probably reflected the greater influence of biological interactions, including predation and competition with spasmodic settlements of *Mytilus*, and this may account for the drop observed in the late 1980s.

Reference to natural conditions: Before recovery can be assessed, the unaffected condition must be considered. The eulittoral of exposed shores of Devon and Cornwall is normally characterised by small-scale spatial and temporal fluctuations in the major components of fucoids, barnacles and limpets. Isolated patches of *Fucus* occur, but they are never more than clumps of a few plants and total cover rarely exceeds 10 to 20%. The patchiness and fluctuations are partly generated by variation in recruitment and small-scale differences in microhabitat, predation and physical disturbance. Therefore, "recovery" can be defined as a return to levels of spatial and temporal variation seen on unaffected shores.

Subsequent damped oscillation: After the initial massive increase in *Fucus*, and a similar but aphasic increase in the key herbivore *Patella*, subsequent fluctuations have been much smaller. *Fucus* cover was clearly abnormal for the first 11 years, and was perhaps slightly elevated in the early 1980's, before fluctuating around normal levels after 15 years or so. The abundance and population structure of *Patella vulgata* were clearly abnormal for at least 10 years, probably 13.

Time scale for recovery: The time scale for recovery at these sites seems to be at least 10 years. If limpet population structure and barnacle densities are used as criteria then 15 years may be more realistic. These time scales are not surprising when the long life spans of the main organisms are considered: *Fucus* 4-5 years, *Patella* up to 20 years, but usually < 10 years, and *Chthamalus* at least 5 years and possibly 20. If we estimate that the average life span of a limpet is 7-10 years it is highly likely that population structure will take 15 years or so to stabilize.

The time scale for recovery is clearly much longer than was thought by many ecologists in the early 1970s. Dense growths of seaweeds were seen as a sign of recovery, rather than of a highly disturbed community, and there were suggestions that the system had returned to normal within two years. Even the more pessimistic considered that only a few more years were needed for a complete return to normal, but Southward and Southward (1978) rightly dismissed optimistic forecasts and the myth of rapid recovery. At that time, they could only assert that some shores heavily treated with dispersants had not returned to normal after 10 years, whilst many had taken at least 5-8 years. It is now clear that it may take 15 years or so for the worst affected shores to recover. In contrast, recovery at the only shore where oil was substantially untreated because of its proximity to a seal breeding area (Godrevy) was rapid and almost complete within three years.

Toxic effects of dispersants: It was very quickly learnt from this incident that large-scale use of dispersants causes acute toxic effects. In the few weeks taken for the oil to cross the English Channel, a very different approach was adopted by the French and the Channel Islanders - manual removal or the use of suction devices with dispersants applied sparingly. These lessons were absorbed by those in charge of responding to the *Santa Barbara* blow-out in 1969 and subsequent spills such as the *Amoco Cadiz* in 1978, the *Braer* in 1995 and the *Sea Empress* in 1996. Impetus was also given to the development of less toxic dispersants (NAS 1989) and to physical dispersal and mechanical collection. In most instances, manual methods (whether removal of oiled plants or use of absorbent materials) seem to cause less disturbance than that associated with the trampling and movement of equipment, vehicles and vessels during mechanized operations.

During recent spills, there have been trials of methods which enhance the microbial breakdown of oil (see Swannell *et al.*, 1996 and Mohammed *et al.*, 1996 for reviews). These methods have proved successful although operational limits on their use have not been fully defined.

F. INTRODUCED SPECIES

Three of the main species affecting rocky shores in the UK are described below. The accidental introduction of non-native species is probably the most difficult anthropogenic impact to control. Fouling species can be transported as adults on the hulls of ships, while larvae and propagules can survive in ballast water and species introduced for aquaculture can bring other species with them. The impact of an introduced species on shore communities varies from case to case.

1. The Australian barnacle Elminius modestus

The Australian barnacle *Elminius modestus* was probably introduced into UK waters by shipping during the second world war (see Lewis, 1964, for review). It rapidly spread around the UK and mainland Europe and is now abundant in estuaries and bays. It can displace native barnacle species. However, native species perform better than *E. modestus* on more exposed coasts and these populations provide larvae which settle on available space on sheltered shores. Apart from a slight reduction in the populations of native barnacles, *E. modestus* seems to have had little effect on the structure of rocky shore communities. Recruitment variation and natural disturbance allow the coexistence of a mixed barnacle fauna.

2. The Japanese brown macroalga, Sargassum muticum,

The Japanese brown macroalga, *Sargassum muticum*, was introduced to Europe as a result of oyster transplantation. It spread rapidly thanks to floating fragments capable of reproduction. It is now common on the South coast of England, dominating low shores with a broken stone or boulder substratum. It also grows in deep rock pools. The progress of the species was hindered for a long time by the natural geographic barrier of Lands' End, but it has recently started to spread up the north Cornish coast. *S. muticum* grows quickly and can clog coastal waterways. In most of the areas where it grows, *S. muticum* does not seem to compete directly with native species. However, it might have displaced *Chorda filum* from unstable habitats and reduced the abundance of *Cystoseira* spp. and *Halidrys* spp. in low shore pools. *S. muticum* provides an ideal microhabitat for many epiphytic species and its presence can sometimes enhance species richness (Withers *et al.*, 1975; Critchley *et al.*, 1990).

3. Japanese seaweed, Undaria

Of greater concern is another Japanese seaweed, *Undaria*, which was deliberately introduced to the French coast and has recently been found on UK shores (Fletcher and Manfredi, 1995). It is a very vigorously growing kelp, has the potential to displace native species, and is spreading quickly along the south coast of England.

Little attention has been given to assessing the types of community that are at risk from introduced species. Gray (1986) identifies the occurrence of 'bare areas' as an important feature. Such bare areas occur periodically on all rocky shores, even with low levels of disturbance. Since current understanding of the ecology of invasion is very limited, it is sensible to consider that all communities are at some risk (Holt *et al.*, 1995).

G. COASTAL CONSTRUCTION

Natural shorelines are replaced with artificial substrata for a variety of reasons. The most extensive changes result from the building of coastal defences. Land reclamation schemes and many waterfront developments including harbours, marinas and even residential complexes, involve the introduction of an artificial substratum into the littoral zone. Sea defences are most likely to be built on depositing shore lines and consequently they increase the substratum available to rocky shore species. However, the ecological value of these artificial substrata depends very much on their design.

Colonisation of virgin artificial substrata and subsequent succession is similar to that observed on natural substrata (Hawkins *et al.*, 1983; Cannon, 1997). The time for a 'mature' community to develop is therefore expected to depend on the scale of the development. Smooth sea walls have limited topographical complexity and therefore, provide little in the way of microhabitats. As a result, an impoverished community might be expected on these structures. However, more complex hexagonal blocks and tetrapods which are sometimes used for the construction of coastal defences may provide abundant microhabitat space which could lead to a greater diversity than is seen on natural substrata. Studies of the fauna associated with artificial reefs made from concrete and stabilised coal ash have suggested that there is no substantial biological risk associated with leachates and bioaccumulation of toxins from these materials.

H. KEY POINTS

- Generally, the effects of chronic impacts on rocky shores are reversible provided the disturbance is stopped. Recovery from acute impacts is also possible but may take much longer depending on the scale of the impact. Opportunistic studies following acute impacts such as the *Torrey Canyon* disaster have improved our understanding of the processes of recovery in rocky shore communities. Recovery is a return to the structure and dynamics of unaffected communities. It is apparent that some baseline data are necessary to determine what constitutes the unaffected condition for any particular shore.

- An impact on a particular species within a rocky shore community can potentially affect the structure of the whole community. This is particularly likely when key species (see chapter III) are affected.

- Not all anthropogenic impacts have a negative effect on the biodiversity of rocky shores. Introduced species and artificial substrata have potentially positive effects. However, coastal constructions, in particular, represent a threat to sediment shore ecosystems.

- The management of SACs should aim to reduce impacts wherever possible. This presents a particular difficulty in the case of recreational impacts. Conservation efforts depend heavily on public co-operation and the benefits of allowing public access are considerable. Management schemes should aim to prevent unacceptable impacts by restricting access as appropriate.

VI.
MONITORING AND SURVEILLANCE OPTIONS

A. INTRODUCTION

The management of Marine SACs is intended to minimise the impact of human activities on the site, especially those features with conservation value and respective conservation objectives. Each site will need a programme to monitor the condition of interest features and assess the effectiveness of management measures. Such programmes should therefore provide sufficient information to determine the expected condition of shores in the absence of major human impacts. They should then regularly assess the condition of shores to check for degradation or change. They should also determine whether activities close to or within the SAC are having an impact on the shores.

The study of rocky shores has a long history testing ideas about ecology and recovery. Several features of rocky shores have made them ideal systems for developing and testing ideas about ecology. It has also been recognised that monitoring rocky shore communities is a convenient method for assessing various environmental impacts. As a consequence, numerous monitoring and surveillance options exist (see Lewis, 1976; Hiscock, 1985; Baker and Wolff, 1986; Raffaelli and Hawkins, 1996). Following from the SACs biological monitoring handbook (Hiscock, 1998), surveillance is defined as “a procedure by which a series of surveys is conducted in a sufficiently rigorous manner for changes in the attributes of a site (or species) to be detected over a period of time”. Monitoring is defined as “surveillance undertaken to ensure that formulated standards are being maintained” (Hellawell, 1978), with the standards determined in advance. This chapter discusses the need for surveillance and monitoring of rocky shores and outlines some of the options available.

It is emphasised that the appropriate method can be chosen only after careful consideration of the question being addressed and the resources available. Consideration must be given to the scale, frequency, timing and resolution of surveys. Wherever possible monitoring should be undertaken in a hypothesis testing framework to disprove no change if testing for changes, or disprove changes if seeking to demonstrate no change.

B. GENERAL CONSIDERATIONS

1. Accessibility

The littoral zone is the most accessible of all marine habitats. Since many rocky shore organisms can be easily identified *in situ*, non-destructive surveillance is usually possible (e.g. Lewis, 1976). Rocky shore monitoring therefore provides a cheap and efficient means of assessing the condition of coastal ecosystems.

2. Biological and Physical characteristics

Physical and biological characteristics of the shore and the relationship between them should be recorded whatever the ultimate aim of sampling. Important physical factors include shore elevation, wave exposure and topographical structure (see Chapter II). Many surveillance techniques treat the shore as two dimensional. Estimates of species or population density are based on the unit area surveyed. As topographical complexity increases, so will the surface area of the rock within a quadrat (Kostylev *et al.,* 1996). Not accounting for surface complexity could introduce bias into surveillance data.

3. Survey design and frequency

Sampling conducted on a single visit to the shore can answer questions about the community structure at one instant. Relevant questions might concern the types of organisms present and the abundance and distribution of each species. In order to determine the effects of natural events or human activities on ecological communities, it is important to determine how they change in response to these factors. Monitoring and surveillance schemes test the hypothesis that communities do not change over time. The obvious requirement of such schemes is repeated sampling. It is important to select the time of year and frequency of survey which will best meet the study objectives, and to repeat surveys at the same time each year to avoid confusing seasonal with interannual changes. A good time for such visits is between late summer and autumn, by which time the year's cohort of most species will have settled. In the highly unlikely event that seasonal patterns are to be described, monthly or bimonthly sampling would be needed. A sampling frequency as low as four to six times a year would give some idea of seasonal differences between years.

4. Biological variability and stability

Many communities are immensely variable in the absence of man-made perturbations. Such natural changes might result from biological effects. For example competition for space, grazing, predation, and recruitment variation can all affect the relative abundance of organisms (Chapter III). Alternatively, changes can be caused by physical perturbations such as storms, prolonged shifts in wind direction and unusual temperatures (Lewis, 1985; Chapter IV). The effects of biological interactions are often localised, while changes due to physical factors usually affect much larger areas.

Those shores which show the greatest degree of natural fluctuation are easily perturbed in experiments. They are therefore likely to suffer the greatest impact from anthropogenic factors. This creates the non-trivial problem of detecting anthropogenic effects against a background of biologically induced fluctuations (Hawkins *et al.,* 1985). It is certainly worth conducting surveillance on these shores. Good design is of paramount importance. Impacts close to the site of a pollution source might be easy to detect if they cause gross deviation from natural cycles.

However, a formal surveillance scheme (Section VI.D, p54) should be used to identify more subtle, chronic or widespread impacts with a good degree of certainty. Surveillance should be carried out at several sites at different distances from sources of potential impact. A comparison of the results from each site will allow a sensible judgement to be made about the cause of observed changes. Attention should also be given to previous studies of disturbance and recovery (e.g. the aftermath of the *Torrey Canyon* oil spill, Chapter V) and to studies of the natural dynamics of rocky shore communities (see Chapters III and IV for further discussion). Detection of changes associated with seasonal variation in communities require especially close attention to sampling design: with random sampling within seasonal periods (Underwood, 1997).

5. Distribution of Species

Many southern rocky shore species reach the northern limits of their distributions on the western coast of Britain and Ireland. A smaller number of northern species also reach their southern limits along this coast (e.g. *Fucus distichus anceps* in southwest Ireland). Past records have shown that some of these limits respond to climatic change, both gradually (e.g. Southward, 1991) and rapidly due to unusually extreme weather (e.g. Crisp 1964). Thus rocky shores provide the potential for monitoring climatic change, provided monitoring is carried out at a series of stations spread over a wide geographic range. The assignment of Marine SAC status to a number of sites throughout the latitudinal range of the British coast and the proper monitoring of such sites could allow the achievement of this aim by providing a network of sites. This subject is discussed further in Chapter VII.

C. MEASUREMENT OF PHYSICAL CHARACTERISTICS

1. Levelling - measurement of tidal elevation

Biological surveys should be conducted at a range of representative levels or at a single defined shore level on the vertical emersion gradient (measured relative to Chart Datum). Heights of sampling stations should be measured relative to known references such as the level of high or low water (from tide tables and adjusted for atmospheric pressure). The level of a sampling station can be assessed by a number of methods (Hawkins and Jones, 1992). Split prism levels accurate to the nearest centimetre are recommended. Cross staff levels developed by the Field Studies Council are reasonably accurate but only give levels at fixed intervals. An interval of ten percent of the spring tide range is recommended (Baker and Crothers, 1987). When possible, the height of each station should be determined in both directions, away from and back to a reference point.

2. Wave action

a) Physical forces of wave exposure

Measurements of the maximum forces generated by impacting waves have been made on rocky shores by fixing to the rock surface various gauges, meters or force transducers (Field 1968, Jones and Demetropoulos 1968, Harger 1970, Denny 1982, 1983, Palumbi, 1984, Underwood and Jernakoff 1984, Galley 1991). The long-term (>1 year) frequency distribution of wave forces would be the most useful descriptor but such measurement schemes are hardly feasible. The rate of dissolution of balls of plaster of Paris has been used to get an idea of water movement and breakdown of the boundary layer near to organisms (Muus 1968). Recently, various force transducers have become more cheaply available and microcomputers can easily handle the vast amount of data generated (Denny 1982, 1988).

b) Biological indicators of wave exposure

Biological indices (e.g. Ballantine, 1961, see **Figure 1**, p28) can be used to give a quick estimate of exposure. These are based on extensive knowledge of the effects of exposure on the biological community of the shore. Thus changes in the distribution of certain species will give an indication of changes in wave action. Indices may only be locally applicable (Crothers, 1983). Such scales contain an element of circular reasoning: estimates of exposure based on the distribution and abundance of species should not be used to relate community structure to wave action.

c) Map-based estimation of wave exposure

Where direct measurements are not possible, map-based methods are recommended. In general terms, wave action increases with fetch, the distance of open sea between the shore and the nearest land. Map based methods (e.g. Wright, 1981, described in Baker and Crothers, 1986) involve a measure of fetch and the angle open to the sea. The exposure index is often modified to take account of such factors as the width of channels, sea depths and the strength and direction of prevailing winds. Some quite complex indices can be found in Thomas (1986). A simple alternative is to measure the angle open to a fetch of 5 or 10km. Shores with greater angles have a higher level of exposure.

3. Physical structure and Topographical complexity

One of the best ways to minimise differences due to topographical complexity is to position sampling stations on areas of similar substratum. This will usually be free-draining bedrock unless information on specific microhabitats is required. Whether or not this is possible depends on the design and intended analysis of the sampling scheme. It is perfectly acceptable to place a transect entirely on bedrock. It might be necessary to break up the transect in order to avoid other microhabitats like boulders and rock pools. When the transect reaches one of these features, a new one should be started as close as possible at the same shore level. If this is not done it might not be possible distinguish between the effects of the emersion gradient and microhabitat variation. When conducting stratified random sampling, deliberately placing the quadrat in a chosen location is not permissible. When a quadrat lands on a rock pool, for example, it can be rejected. Alternatively, it can be counted but scored as being in a pool to allow determination of the incidence of the different microhabitat types.

The structure of a site can be described in a number of ways. Most obvious is a descriptive account of the rock type and its main features. A sketch map will help with this. An index of rugosity, the roughness of the rock surface, can be obtained using a length of chain, rope or string. The line is run between two points, along the contours of the rock. It is then pulled taut between the same points. The length along the surface is then divided by the taut length. The resolution of this method depends on the thickness and flexibility of the chain or string used. Similar indices can be obtained using profile gauges. Several methods are compared by McCormick (1994). The methods described by Kostylev *et al.* (1996) can be used to describe surface complexity in terms of fractal dimension but are probably too complex for most marine conservation oriented studies.

D. MEASURING BIOLOGICAL ATTRIBUTES

Throughout the history of rocky shore studies, successively more detailed methods have been devised for describing the distribution and abundance of organisms. Pioneers like Stephenson and Stephenson (1949) and Lewis (1964) gave broad scale qualitative descriptions. Later, semi-quantitative techniques, (Crisp and Southward 1958) allowed rapid estimates to be made of the abundances of organisms in particular localities. More recently, quantitative techniques involving prescribed sampling regimes and analytical methods have been used to provide very fine-scale descriptions of distribution and abundance. In addition to these techniques, experiments can be conducted to test specific hypotheses.

Each of the above methods has a role to play in surveillance and monitoring programmes for rocky shores. More quantitative techniques allow changes to be assessed and understood in more detail. However, qualitative techniques provide relatively quick and simple methods for broadscale surveillance which will meet many of the requirements of conservation workers. The level of detail required from any programme will depend of the questions being asked. Therefore, the aims of the study must be made absolutely clear before any descriptive work is undertaken. In parallel experimentation allows hypotheses on causes of change to be tested (Underwood, in press).

1. *Qualitative measures.*

a) General description of habitats and communities

A general, qualitative, description of the shore will be useful in all studies. This should include information on physical and biological factors. A good description of the physical features of the shore should include say whether it is exposed or sheltered, whether it is bed-rock or predominantly boulders, the size of the boulders, whether it is evenly sloping or highly broken and the rock type. A general description of the major communities should say, for example, how many zones are present what shore levels they occur on and what are the dominant space-occupying organisms in these zones. The MNCR biotopes classification (Connor *et al.*, 1997) provides a standardised format for describing the communities and habitat features present (see Chapter I). This will allow for a degree of objective comparison of reports produced by different observers. However, fieldworkers should be aware that some of the community-habitat combinations they encounter may not be covered by the biotope classification. Users of this system should be careful to avoid misclassifying biotopes.

b) Photography - recording physical appearance

Photographs or video will provide an instant record of the gross features of the shore community. Photographs taken on different site visits can be compared with assess any large scale changes in the shore community. Fixed viewpoint photography, where an area is photographed from the same position at each site visit, allows unambiguous comparisons. Aerial photography allows unobstructed views of whole shores and for very rapid coverage of many shores in a single flight. Infra-red photographs can be used to distinguish chlorophyll bearing algae from a background of similarly coloured rock. The advantages of these methods are that they allow broad coverage and that data is easily obtained and stored as photographs. Gross changes can be easily detected. The disadvantages are that subtle changes will not be recognised and that comparison with other areas is impossible. Understorey and encrusting species can be obscured by taller organisms and only species which occupy large areas will be detected. Aerial photography has the obvious disadvantage of cost. Electronic cameras are rapidly becoming cheaper and may offer significant advantages over conventional photography with rapid digital archiving capabilities and potential for image analysis.

Correct interpretation of photographic records will rely on some degree of ground truthing. We strongly recommend that the time available during a site visit is used to collect numerical data on the community, which will provide more detail and facilitate statistical analysis.

2. Detailed surveys of abundance and distribution of biota.

Conducting a detailed survey therefore represents an efficient use of the time available during a site visit. The level of detail will depend on the information required. Numerous surveying methods have been developed, a few of which are described below.

All numerical methods aim to provide a description of the abundance of certain species at different positions on the shore. Both physical and biological information should be collected.

In many cases, as with fixed transects and quadrats, most of the physical information needs to be collected only once.

a) Key species.

Some species which are present on rocky shores will be too small, too rare or too well hidden to be detected whichever sampling method is used. Biological sampling therefore provides an index of the condition of the community but not a thorough description of its composition. Monitoring aims can often be achieved by restricting surveillance to a number of important species (Lewis, 1976). These species should be easy to identify with the minimum of disturbance and should play a key role in the community. That is, the abundance of these species should affect and be affected by the abundance of other key species. Recommended species are those which dominate available space such as macroalgae, barnacles and mussels, and grazers such as limpets and important predators. Dogwhelks are an important indicator species for the effects of TBT (see Chapter V) while various species of barnacles, limpets, winkles and topshells could be used for monitoring climate change. It should be possible to assess the abundance of 15 to 30 species during a single shore visit. We therefore recommend that the number of species used should be in this range with a high number being used where more detail is required. Sampling should be non destructive wherever possible. Destructive sampling will, however, be unavoidable when specimens are required for analysis elsewhere and when sampling the fauna associated with algae or sheets of sessile animals. Fieldworkers should select target species and sampling methods to minimise potential impacts of these methods on the shore community.

The key species approach is less time consuming than producing detailed inventories of all species present. It will not, however, provide information on species richness. When using the key species approach, a smaller number of species means that more sites can be sampled per unit time and *vice versa*. It is important to reach a balance between species and spatial information which allows the objectives of the monitoring or surveillance programme to be met.

b) Abundance measures.

There are several methods for assessing and recording the abundance of chosen species within sampling stations. The **semi-quantitative approach** of Crisp and Southward (1958) has proved valuable, allowing a quick assessment of the abundance of organisms at a particular locality. Abundance is described by one of a limited number of terms, usually between five and eight. Such scales are usually based on a logarithmic or semi-logarithmic progression. In order to minimise between-observer variability, it is best to do a few counts in quadrats of various sizes before beginning a survey. This will give a good idea of the appearance of the various abundance levels.

One way to estimate an index of abundance for rare or inconspicuous species is to conduct a **timed search** within predefined sampling stations of fixed area. This is particularly appropriate for highly heterogeneous shores, especially those made up mainly of boulders. It is also appropriate for assessing microhabitats such as rock pools, crevices and the underside of stones within a predominantly bedrock shore. Personnel with experience in identifying the species of interest should be able to search an area of about 20m^2 within 15 minutes. This method is subject to between observer variation and at best it provides an index of abundance rather than an absolute measure.

The **actual numbers of each species**, or the area it covers can be recorded within **quadrats**. **Cover** can be estimated using the subdivisions of a quadrat as a guide. A better and more objective way of estimating cover is to use the percentage of "hits" underneath the cross-wires of a quadrat, or the dots or holes on a transparent overlay sheet. A double layer of sighting points avoids parallax errors. Alternatively, a **pin-frame** can be used, which is more precise but cumbersome. Good estimates can be made with 25 or more sighting points: the larger the number, the more accurate the estimate (30-50 seem appropriate for most cases). These sighting points can be arranged regularly or randomly. For most purposes regular arrays are probably best. Random or regular dot overlays can be used to measure percentage cover on photographs. In recent years, PC-based digitizers or image analysis systems have become much cheaper and are excellent for estimating cover from photographs (see Foster et al., 1991, Meese and Tomich, 1992). Data can be entered directly into statistical packages for analysis. Limited time available for field work will often preclude the use of detailed methods. A visual estimate of percentage cover is a very quick method. Tests have shown that there is strong correlation between visual estimates and actual cover. With a little practice, most observers should be able to estimate cover within 20% of the actual value. A recent detailed assessment of various approaches is given in Meese and Tomich (1992). The various kinds of cover: canopy cover of large seaweeds, understorey cover by turfs of algae and sessile animals, and encrustations on the rock surface itself should be considered separately. An estimate of cover can be converted into an estimate of abundance by multiplying the density of the species by the area it occupies.

The main **disadvantage of the abundance scale approach is the limited scope for analysis**. Usually, this method is used to estimate abundance for a whole site, in which case, no estimate of within-site variance is possible. However, it is possible to use this method for estimating abundances within quadrats at a site, although the main problem then becomes the limited detail. Analysis with non-parametric techniques is necessary despite their limited power. Surveillance and monitoring methods using abundance scales are less likely to detect subtle impacts than the more quantitative methods using counts of individuals or area covered. Quantitative methods are more amenable to statistical analysis. Standard parametric statistics requires that the variances are the same in the areas under comparison. Usually this is not the case and some form of transformation has to be applied to the data (Underwood, 1981; 1996). The power of any analysis is limited by the accuracy of the data. The collection of accurate data is time consuming. There is therefore a trade off to be made between the time available for sampling and the level of detail required.

3. Design

A description of the zonation of organisms on the shore is a useful first step towards describing the community. The shore should, at the very least, be divided into areas representing different tidal heights.

a) Quadrat size

Many sampling designs are based on abundance estimates from quadrats. The appropriate size of quadrat to be used depends on the size of the organisms of interest. A 1m x 1m quadrat is usually best for large seaweeds such as *Ascophyllum* or kelps. Smaller quadrats may be more appropriate for smaller organisms. For example, 50 x 50 cm is suitable for British limpet species and a 5 x 5 cm quadrat is recommended for sampling barnacles. As a general rule, the appropriate size of quadrat should enclose no more than about 100 individuals of each species at the densities normally encountered. Greater numbers will take too long to count. With too small a quadrat size there will be problems with zero counts. Sampling at any shore level will therefore normally involve the use of several different sized quadrats or subsampling within subdivisions of a large quadrat.

b) Method of choice

Shores consisting primarily of bedrock are amenable to quadrat sampling while boulder shores generally are not. Within-quadrat estimates of abundance should be made using either absolute numbers of individuals or percentage cover rather than using semi-quantitative abundance scales. Timed searches will generally rely on abundance scales although replicate 5 or 10 minute searches can be used. Quadrats, being generally smaller than the areas in which timed searches are conducted, allow easier use of designs involving repeat random sampling. Subject to these constraints, the design alternatives described below can apply equally to the areas within which timed searches are conducted as to quadrats.

c) Design of sampling schemes

The design of a sampling scheme will depend on the information required from it. The design will be limited by the resources available. Where a single worker is required to survey one or more shores during a single low tide, the design options are limited by what can reasonably be accomplished in this time. It is also good practice to consider the analytical techniques to be used before deciding on the final design. Some idea of community structure and dynamics can be gained without formal analysis. However statistical methods, when properly used, have several advantages over the former approach. Not least among these is the possibility of extracting relevant information from large data sets. An enormous amount of data might be generated through the long term monitoring of up to 56 SACs. Thus, monitoring strategies which allow these data to be collected in a way which is amenable to statistical analysis will maximise the value of the resulting information. Statistical analysis also allows the identification of sometimes subtle changes and the scales at which they are occurring.

d) Fixed-location quadrats

The use of **fixed-location quadrats** (Lewis, 1976) was widely adopted during the 1970s. Using this method, the abundance and distribution of organisms in a limited number of fixed sites can be regularly recorded. This approach has been used to study changes within such fixed stations (Hartnoll and Hawkins, 1985). However, the major disadvantage of fixed quadrats is that they are rarely replicated, and even when they are replicated, sequential measurements cannot be treated as independent of each other in statistical tests. It is therefore not possible to draw any conclusion about spatial scales larger than the sampling station. However, when species are rare, they may well escape detection using random sampling methods. It is therefore recommended that when rare species of conservation interest are identified, fixed stations should be established to monitor their condition. The abundance of these species on the rest of the shore can be estimated from random sampling.

e) Grid-based methods (systematic sampling)

Localised maps of species distribution and abundance can be produced by sampling at regular intervals within a grid (Johnson *et al*., 1997). However, this technique is not recommended for making comparisons with other areas as the quadrats are unlikely to be separated by a large enough gap to make them independent of each other. A comparable technique which is useful for mapping the absolute vertical distribution of organisms is to use a **thin transect** with contiguous quadrats. The limitations are similar to those for regular sampling because of a lack of independence. The problems which arise from this are discussed by Legendre (1993) and Schneider and Gorewich (1994). The choice of quadrat size is an important consideration when using thin transects to describe zonation. Extremely narrow transects might give a false idea of the abundance and vertical range of species. Very wide transects might include variation caused by the horizontal wave action gradient. Replicated thin transects may be the best option if the main interest is in zonation but are unlikely to be feasible in the time available for a shore survey.

f) Stratified random sampling

The design that best facilitates statistical analysis is stratified random sampling. The strata are areas of interest which might be compared in the analysis. Within each of these strata, subsections are sampled at random. The distance between each successive quadrat is determined using tables of random numbers. It is likely that conservation workers and researchers will wish to compare communities at various levels on the shore, in which case the strata are these levels. Comparisons may be made at a variety of spatial scales using nested sampling. Nested sampling schemes have proved extremely useful in detecting the scales of spatial variation in abundance of rocky shore organisms (Caffey, 1985, Underwood and Chapman, 1996). A nested sampling design consists of sampling units repeated at a number of predefined spatial scales. An example of such a scheme appropriate to surveying SACs would consist of a sampling unit of a group of quadrats at a defined shore level (say mid tide level) repeated at three to four 100m intervals within a single location (a 'shore') in an SAC. Several shores could be surveyed in this way in a larger SAC, while a repeat of the design at different SACs would permit a rigorous analysis of the variation in dominant species among SACs. Recent studies adopting this procedure have shown that variation is most pronounced at scales of up to 2m (microhabitat patchiness) and at 10km and beyond (between shore variation: Underwood and Chapman, 1986).

g) Division of sampling effort

It is likely that workers will also wish to monitor changes which occur. Two major design aspects of the sampling scheme are the number of shore levels to be considered and the number of samples to be taken in each.

The **number of shore levels** is determined by the resolution of the study and the time available for surveillance. Biogeographic mapping projects might concentrate on three major zones; high, mid and low shore or at the zone of maximal abundance of the species under study. Greater resolution might be required when assessing environmental impacts or producing detailed local information. There is a need to balance the number of species used with the number of sites surveyed. More sites allow greater spatial resolution while more species provide greater detail on community structure. However, a finite amount of data can be collected and analysed in the time available. It should normally be possible to sample at 5 or 6 shore levels during a single site visit. In monitoring programmes, sampling stations should initially be located by levelling along vertical transects. The position of these transects can be relocated either using detailed photography or markers fixed into the rock (See Appendix 7 in Hiscock, 1998)

The purpose of repeated sampling in each station is to gain the best estimate of the mean and variance of the abundance for each species or of diversity. The best **number of samples** to use should balance this need with the need to avoid excessive sampling effort. A pilot study at the outset of a sampling programme can be used to determine the correct number of samples. This pilot study should consist of a survey using a large number of quadrats; say, 20 per shore level. These should be placed in random order and the cumulative mean and its confidence limits plotted against the number of samples which gave that estimate. Eventually the fluctuations on the graph will damp down, showing the number of quadrats required to reach a reasonable estimate. It is unlikely that conservation workers will have time to do this for each site, especially when several quadrat sizes are being used. Where possible, a pilot study should be conducted at a representative site. When this is not possible, a rule of thumb is to use as many quadrats per station as possible within the time available. A minimum of three quadrats per station will facilitate analysis. More will probably provide better estimates.

Table 5. Summary of recommended approaches to surveying rocky shores

Intention	*Recommended Technique*
Mapping of shore biotopes or habitats.	Sampling at regular intervals within a grid.
Absolute vertical distribution of organisms.	Vertical transect with contiguous quadrats.
Monitoring rare species.	Fixed quadrat.
Monitoring natural change in a small area.	Fixed quadrat.
Monitoring of abundance of key species at different spatial scales.	Repeat random sampling (Nested sampling). (Quadrats for bedrock, timed searches for boulders, rock pools and crevices).

E. MONITORING TO DETECT IMPACTS

Because they are easily studied, rocky shores provide a means of assessing changes which may reflect effects in other marine communities. This principle has been used by OPRU to monitor the impacts of operations at the Sullom Voe oil terminal in Shetland. More recently several publications have appeared which have developed a solid scientific framework for impact assessment (e.g. Stewart-Oaten *et al*., 1986; Underwood 1991; 1992; 1995). When new activities begin within or close to SACs, any potential impacts on conservation features should be assessed.

The abundance of almost any species will fluctuate over time. Abundances will also fluctuate from place to place. Perturbations of human origin may be judged to have had an impact when they alter the scale of these fluctuations over space and time. In many cases an impact results in changes in the mean abundance of species. For example, the average number of dogwhelks close to an effluent outflow might be low compared with other areas and to the same area before the installation of the outflow. It is also possible that an impact could alter the magnitude (variance) of fluctuations without affecting the mean abundance (Underwood, 1991). In order to identify the presence of an impact with a high degree of statistical certainty, it is necessary to establish a link between the presence of the factor causing the impact and the observed fluctuations in abundance of target species. The abundance should have changed after the appearance of the supposed impact, in a way which is not predicted by changes at other similar sites.

1. Before/After, Control/Impact sampling design

The BACI (Before/After, Control/Impact) design was proposed by Bernstein and Zalinski (1983) and Stewart-Oaten *et al* (1986) as a means of assessing impacts. Measures of species abundance would be taken at two sites (the site of the putative impact and a similar, control, site where no impact was expected) on several occasions both before and after the onset of the putative impact. Repeated measurements allow a determination of whether observed changes at the site of the putative impact are part of the pre-existing cycle of change. The control site is intended to show whether any observed disruption in this cycle is part of a wider effect not due to the putative impact. The use of a single control led to criticism of this method (Underwood, 1992). A natural change at the control site which was coincidentally similar to that caused by the impact at the other site could lead to the impact going undetected. Alternatively, a change at the control site from before to after the onset of the putative impact while the other site remained unchanged, could result in an impact being diagnosed where there was none. The solution, proposed by Underwood (1992), is to use several randomly-selected control sites. Thus the effects of global trends can be separated from those of natural fluctuations within individual sites. Further details on the design and analysis of this type of sampling programme can be found in Underwood (1991; 1992).

F. KEY POINTS

- The effective management of Marine SACs and other conservation areas will depend on well designed and executed surveillance and monitoring schemes. Monitoring is needed to detect responses to anthropogenic impacts and to assess the effects of site management schemes. Rocky shores are the most accessible marine habitat and can be surveyed cheaply and non destructively. Rocky shores can therefore be used to assess the general condition of coastal ecosystems.

- Many rocky shore communities undergo a great deal of natural change. Monitoring and surveillance schemes should be able to distinguish between natural and anthropogenic changes. Although the MNCR biotope classification allows shores to be characterised at a given instant, it is not intended to track natural changes in community composition. We advocate a hierarchical approach: starting with broad scale quantification and qualitative description but using a numerical approach which will allow the application of statistical analysis whenever possible.

- Existing sampling and analysis techniques are sufficiently advanced to allow very detailed surveillance and monitoring. However, we recognise that what can be achieved within SACs will be limited by the personnel and time available. Many of the proposed SACs are remote from scientific centres. Monitoring schemes should be planned with attention to information required and resources available. A balance should be made between the scale and level of spatial and biological detail of a study.

- When the aim of a study is to produce detailed inventories of species, or to assess species richness, a thorough assessment of each species must be performed. However, most surveillance and monitoring requirements will be met by focusing on the abundance of between 15 and 30 key species. A compromise must be reached between the number of species used and the number of sites or levels within each site.

- Semi-quantitative abundance scales provide less detail than direct counts of species abundance. However, they allow much faster assessment of a site. We recommend the use of abundance scales within a stratified random sampling design. Fresh abundance estimates for each species should be made during each survey. Timed searches may be more appropriate for rare species. Fixed quadrats are recommended for monitoring the condition of rare sessile species.

- Photography of shores is recommended wherever possible as a quick and convenient record of the gross features of the shore. All monitoring of rocky shores will require some element of physical surveillance in order to relate the observed community structure to such factors as shore height, exposure and rock type. When surveying is part of a large scale mapping programme (for example, biogeographic mapping of the UK coastline), physical information may be provided by Ordnance Survey maps, Admiralty charts or remote sensing. Photographs of the shore will provide a record of the dominant space occupying organisms in each zone. More detailed information will be gained by conducting surveys of the abundance of 15 to 30 key species at three levels on the shore.

- Within SACs, maps should be constructed of biotope or species distributions at finer scales. It is recommended that sites are located 10 km apart and are visited once a decade for surveillance purposes. However, yearly site visits are recommended to monitor the condition of shores within SACs. These visits should be made in the summer or autumn. Surveys should be conducted along fixed transects. Vertical transects should be established and physical surveys conducted along them at the beginning of the monitoring period. The position of these transects can be relocated on return visits either with detailed photographs or using fixed markers. Again, abundance surveys for 15 to 30 key species should be conducted but in 3 to 6 shore levels with replicated transects. Where the use of quadrats is not valid, abundance scales can be used.

- Human activities occurring within or close to SACs should be assessed for potential impacts on shore communities. Surveillance can be conducted using the methods described for mapping within SACs. However, sites should be chosen on the basis of their proximity to the putative impact. Site visits should occur once or twice each year.

VII.
GAPS AND REQUIREMENTS FOR FURTHER RESEARCH

Chapters II and III provide our view of current understanding of rocky shore ecology. Chapters IV and V describe what is known about the effects of natural and anthropogenic disturbance on rocky shore communities. Although the ecology of rocky shores is better studied than that of any other marine habitat, gaps remain in our understanding. The aim of this chapter is to identify some of the gaps most relevant to the conservation management of rocky shores and suggest possible approaches for further research. The protected status of habitats within SACs may make them ideal sites for ecological study.

A. ECOLOGY

The vast majority of research into rocky shore ecology has concentrated on communities inhabiting free draining rock substrata. It has also focused on the sessile or slow moving animals which are visible at low tide. This work has made major contributions to the understanding of littoral ecology and wider issues in ecology, such as the roles of competition and predation in structuring communities. It has also raised new questions about the working of these systems. By contrast, many of the microhabitats found on rocky shores have received relatively little attention. There are, therefore, two major strands of potential research into rocky shore ecology. The first is to increase our understanding of well studied systems and the second is to study systems which have received little attention. To avoid complicating factors, this work should focus on sites which are relatively unaffected by anthropogenic impacts. This work would be particularly appropriate within SACs. Since SACs may prove particularly suitable ecological study sites, links between SACs conservation staff and the wider scientific community could be highly productive. This will provide an additional reason to continue conservation efforts at the sites and ecological research should ultimately prove beneficial to the management of SACs.

Certain groups of species and species assemblages deserve closer attention than they have received. Lichens, for example, may serve as important indicator species of atmospheric polution. Processes underlying the stability and persistence of mussel- dominated communities, algal turf communities, and beds of *Ascophyllum* spp. (which have a very slow rate of recovery from disturbance) are less well understood than, for example, *Fucus*-barnacle mosaics on moderately exposed shores.

1. Microhabitats

An area of research which is particularly relevant from a conservation perspective is the contribution of microhabitats to the biodiversity of the shore. Microhabitats may be of either physical or biological origin. In general microhabitats enhance the diversity of an area by providing additional surface area and resources such as shelter (see Chapter III). The major physical features providing microhabitats on rocky shores are rock pools, boulders, crevices, caves and overhangs. Major biological microhabitats are provided by mussel beds, and algal communities. In particular, rock pools and under boulder habitats contribute greatly to the biodiversity of most rocky shores, yet surprisingly little is known about their ecology.

Characterisation of the communities associated with microhabitats is a first step towards understanding their ecology. Basic work on characterisation of the communities could be integrated into SAC management programmes. This would involve the identification of species present and assessment of the community in biodiversity terms. Attention should also be given to spatial and temporal variation in the abundance of species.

2. Mixed shores

Rocky shore ecologists have usually concentrated their efforts on topographically simple shores consisting of smooth bedrock. Little is known of the dynamics of shores made up of complex mixtures of jutting bed-forms, loose rock and patches of sand, mud or gravel, beyond the effects of physical disturbance in boulder fields (Sousa, 1979) and the effects of sand and shingle scour where sediment shores meet the rocky littoral. Such complex shores deserve close attention, especially to determine the relationship between habitat (and microhabitat) diversity and species diversity.

3. Mobile marine species

Crabs and fish move into the littoral zone to forage when the tide is in. Mobile rock pool species range over much greater areas of shore and return to pools as the tide retreats. Traditionally, the study of rocky shore community ecology has focused on the role of species visible at low tide in structuring the community. It is likely that significant levels of predation from crabs and fish could also have an important effect on community structure. The first stage of research into this subject is to quantify the intensity and spatial distribution of predation from wholly marine species. Progress is being made in this area by the use of underwater television cameras to make direct observations of predator activity (M. T. Burrows, personal observations). While it is unlikely to yield information of immediate relevance to practical conservation of SACs, a better understanding of the underlying dynamics of the community will result.

4. Larval Dispersal

Recruitment variation is an important factor structuring rocky shore communities. Many species have planktonic larvae for dispersal and recolonisation of new areas which depend on tidal and wind-driven currents for transport. Very little is known about the interaction of the behaviour and biology of larvae with the hydrographic processes that affect larval dispersal and, ultimately, larval supply. It is likely that variation in the local hydrographic regime among sites, such as the difference between open coastal situations, headlands, islands, and embayments, will have important effects on community structure, through effects on larval recruitment. Comparison of predictions of physical models of flow with the results of wide-scale mapping of biological communities may reveal hitherto unsuspected effects, beside already well-established effects of wave-exposure and turbidity, for example.

B. IMPACTS

While rocky shores have long been used to monitor impacts in the coastal marine environment, new and potentially devastating impacts are always appearing. The effects of novel contaminants such as ivermectin (see p43) and endocrine disruptors aside from TBT on individual species and whole communities are not yet known. Continued vigilance through experimental testing of these compounds and widespread survey and monitoring is needed to detect effects before they are irreversible.

One potential and relatively simple method to detect community level impacts would be to deploy artificial substrata. Comparison of communities on such artificial surfaces with those on natural substrata in affected and unaffected areas may reveal impacts because the confounding source of variation of the nature of the substratum has been removed.

Research into the design of surveys to detect impacts must continue. It is important that survey designs are flexible enough to detect impacts with an unforseen spatial scale and range of detectable magnitude.

C. MONITORING

Techniques for data collection on rocky shores have not changed radically in the last 50 years. The statistical framework for surveying, monitoring shores, and experimental tests of hypotheses about structuring processes has, however, been a very active area in the last 20 years (Underwood, 1996). These techniques for survey design have not, in general, been applied by conservation practitioners in the UK. The necessity for quick, easy, low-cost and practical approaches to the collection of survey data, as in the MNCR biotopes scheme, has resulted in a divergence between the techniques used by experimental field ecologists and conservation practitioners on rocky shores. There is an urgent need to assess the scientific validity of these new rapid assessment techniques for rocky shore monitoring. The techniques for this validation process already exist and are widely used in studies of the soft-sediment benthos: multivariate statistical analysis of community data and methods of ordination and classification. The raw data on species abundance, or even presence or absence, collected in monitoring or survey schemes could be easily treated using these statistical techniques. Classifications produced by the likes of the Cornell Ecology package TWINSPAN, or the results of ordinations using non-metric multidimensional scaling (N-MDS) could be used to assign communities to types either in the current biotope scheme or in new classifications. Rocky shore ecology lags behind terrestrial and soft-sediment ecology in this respect, partly because many of the patterns are obvious and can be described qualitatively.

There is a need for quantitative measures of topographical complexity of shores. These measures should be relatively simple to apply at each of the various types of rocky shore and at a range of scales. It should be possible to relate species diversity to, for example, the degree of topographical complexity at the 1cm, 1m, 10m and 100m scale for a range of shores.

Methods for rapidly assessing the structure of rocky shore communities need development. While quadrat counts and estimates of percentage cover will always remain the main tools for the rocky shore ecologist, other approaches in wide use in other areas have been neglected. Likely areas for profitable research would include the collection of remote sensing data, from either aerial photography or compilation of on-shore composite mosaics of photographs. More expensive options might include laser altimetry and synthetic-aperture radar for the resolution of meso-scale physical features (0.5-100m). On very small scale, stereo photography may be able to resolve surface features needed for a calculation of small-scale topographical complexity. van Rooj and Videler (1996) give an overview of the technique.

D. KEY POINTS

- Progress in understanding the dynamics of rocky shore communities should continue through experimental, survey and monitoring programmes. SACs should be ideal sites for studying the ecology of communities unaffected by anthropogenic disturbance.

- Close co-operation between conservation managers of SACs and the scientific community should be encouraged.

- Characterisation of communities associated with rock pools, crevices, caves, overhangs, boulders, mussel beds and algal canopies would contribute to the development of conservation measures.

- Effects of hydrography through effects on recruitment to rocky shore communities are poorly understood.

- Research into effects of novel contaminants and other impacts should continue, and would be supported by survey and monitoring efforts at SACs.

- Close attention to statistically-valid designs of monitoring and survey schemes will vastly improve their power to detect anthropogenic impacts.

- Current rapid assessment methods (particularly the MNCR biotope scheme) may be supported in practice by mathematical classification and ordination techniques in wide use in other systems.

VIII.
SYNTHESIS AND APPLICATION OF INFORMATION FOR CONSERVATION MANAGEMENT RELEVANT TO MARINE SACs

A. OVERVIEW

Previous chapters have described current understanding of rocky shore ecosystems, the main anthropogenic threats, the options for monitoring these systems and the major areas which require study in order to improve our conservation efforts. This aim of this chapter is to suggest an appropriate strategy for the management and study of rocky shores within SACs. Before making these suggestions, we first consider the value of rocky shore ecosystems from a conservation perspective. We also consider the practical issues relating to study and management of these ecosystems.

B. THE CONSERVATION VALUE OF ROCKY SHORES

Pragmatic nature management policies should be based on an awareness of the sometimes conflicting demands of development and conservation and the limited resources available to meet conservation aims. The resolution of such conflicts of interest and the allocation of resources should be based on an objective assessment of the 'conservation value' of natural features. Criteria for assessing 'conservation value' remain the subject of debate.

In this section, we discuss whether rocky shore communities fulfil each of Hiscock's (draft, 1998) criteria and some additional criteria which we believe are important.

Hiscock (1998b) states that a habitat, community or species is likely to be considered 'important' in terms of conservation if it is

Rare or restricted in its distribution. Rocky shore habitats are common on the shores of Northwestern Europe and especially the UK. The majority of species belonging to rocky shore communities have extensive geographical ranges. The location of any population within this range will be influenced by latitude, salinity, wave exposure, hydrodynamic factors on a variety of scales and the presence of other species. However, most rocky shore species are found at numerous sites. Rocky shores and their species are neither rare nor restricted in their distribution. However, some types of rocky shores, for example those with a limestone or siltstone substratum are represented by few examples in the UK. The widespread distribution of rocky shores inevitably means that they form part of other habitats such as saline lagoons which are restricted in their distribution. Conservation efforts for such habitats should be at a scale which encompasses a cross section of the component subhabitats. Rocky shores in such areas should therefore be considered part of a rare habitat.

In decline or has it been. Rocky shore communities in heavily industrialised areas such as the Mersey estuary have been severely affected by anthropogenic impacts. These shores no longer support many of the flora and fauna associated with a healthy rocky shore community. There has been no significant recent increase in the loss of rocky shore habitats. The historical loss of rocky shore communities due to anthropogenic impacts is devastating in terms of the local ecology but has little apparent effect on communities of the rest of the UK's numerous rocky shores. However, pollution has caused the decline of some rocky shore species, most notably the dogwhelk (Section IV.B.2, p42). Although the dogwhelk population has suffered local extinction, dogwhelks remain a common species throughout the UK. Acute impacts such as the *Torrey Canyon* oil spill have devastated rocky shore communities on long stretches of coastline. These communities have a demonstrable capacity for recovery due largely to the supply of larvae and propagules from more distant populations. The whole U.K. rocky shore habitat is not and has not been in significant decline.

A high proportion of the regional or world population or extent. The UK coastline comprises a significant proportion of Europe's rocky shores. Shores in the Baltic have suffered considerable anthropogenic impact. Those in the North Sea lack the high diversity of species seen on Atlantic coasts. The UK is also the meeting point between the distributions of many Northern and Southern species. Therefore, the rocky shores of the UK and especially those on the West coast are very significant from this point of view. Rocky shores within individual SACs do not represent a high proportion of the regional extent.

A keystone species providing a habitat for other species. Many of the dominant species on rocky shores do provide habitat for other species. Significant examples include mussel beds (Seed, 1996), algal canopies (Section III.D, p30), beds of red algae and *Sabellaria* reefs (the subject of another SAC review). Many species in rocky shore communities, especially grazers, predators and major space occupiers also have a significant effect on other species through their biological interactions. Therefore, many of the dominant species on rocky shores fulfil this criterion.

A biotope with a particularly high species richness. Since rocky shore biotopes rarely exist independently of other units of the community and may not be stable in time, conservation of individual biotopes does not appear to be a workable strategy. The rocky shore community consists of a number of zoned species assemblages arranged along a fairly narrow strip. The diversity of species within this is influenced by each of the major gradients which affect the habitat; wave action, emersion, latitude and salinity. Species richness may not be the most appropriate measure of biodiversity on rocky shores since many bedrock shores are dominated by large numbers of a few species. However, rocky shores, especially those rich in microhabitats, include a diverse array of species in a limited area.

Particularly good or extensive representatives of their type. The general comments on UK rocky shores made in section VII.B. above apply equally to this criterion. UK rocky shores are both extensive and important. Intertidal reefs are noted as a major feature in four out of 12 demonstration SACs and eleven out of 56 potential SACs (Firth of Lorn, Flamborough Head, Lochs Duich, Long and Alsh, Papa Stour, Pembrokeshire Islands, Lleyn Peninsula and the Sarnau, South Wight Maritime, St Kilda, Thanet Coast and The Lizard). Lochs Duich, Long and Alsh include particularly good examples of sheltered rocky shores. The Pembrokeshire Islands include good examples of exposed rocky shores. Papa Stour and St Kilda also include very exposed shores with a strong oceanic influence, while the Berwickshire coast has good examples of North Sea shores. The rocky shore communities of the Firth of Lorn, the Thanet Coast and the Isle of Wight are of relatively low biodiversity while those of the Lleyn Penninsula have a high diversity. Thus, the rocky shores of some Candidate and Qualifying SACs fulfil this criteria while others do not. The UK coast includes plenty of examples of biologically diverse rocky shores which are not contained within potential SACs.

A habitat or community could also be considered to be 'important' if it is:

Of significant economic value. Rocky shore species, especially winkles, edible crabs and seaweeds (fucoids and kelp) are all harvested commercially from UK rocky shores. Rocky shores also provide important habitat for corkwing wrasse which are used in the aquaculture industry. Management policies for SACs should prevent practices, including harvesting, which are likely to result in significant impacts to species or communities. Immigration from protected areas can replenish stocks of animal species in areas where they are exploited and natural recovery of seaweed crops occurs where these have been harvested carefully (*Ascophyllum* spp. and *Laminaria hyperborea*). Since the rocky shores which would be encompassed within SACs represent only a small fraction of this habitat in the UK, it is unlikely that they would play a major role in preserving stocks of commercially important species.

Of aesthetic, symbolic or recreation value. The only benthic habitats which many people will see first hand are those in the littoral zone, which consequently have a higher aesthetic value. Sandy beaches are popular with the public as traditional recreational areas. Although rocky shores are less popular, they can be used by high numbers of visitors (Fletcher, 1997). The value of rocky shores as a teaching aid is demonstrated by the many field trips run by schools, colleges and universities. We feel that the success of conservation projects relies heavily on public involvement and goodwill. Rocky shores are a natural feature of some potential SACs that can be used to promote public awareness of marine ecosystems and generate support for the conservation objectives of the site.

Ecologically important to other species or communities. Rocky shores are net exporters of energy to both marine and terrestrial ecosystems. They provide food to shore and sea birds, otters and marine fauna. They also represent an important seasonal food resource for migrating shorebirds such as the purple sandpipers, *Calidris maritima*. However, there are no known examples of species living in other habitats that rely exclusively on rocky shores for food.

Littoral habitats are unique amongst all marine habitats in their degree of accessibility. Both the public and those involved in study or management of the shore can get direct access without the need for specialist equipment or training. The majority of species associated with sediment beaches are infaunal and must be sampled using time consuming, destructive methods. In contrast, the dominant species on rocky shores are exposed and visible at low tide. The condition of the community can be rapidly assessed using non-destructive methods. Rocky shore communities are well studied and understood. They can therefore be monitored easily and meaningful conclusions can be drawn from the results of this monitoring. Impacts on rocky shore communities may be indicative of wider impacts affecting the marine community. Therefore, **the main conservation value of rocky shores lies in the accessibility of their biological communities and the benefits of this to monitoring programmes and public involvement.**

C. THE MAJOR THREATS TO ROCKY SHORE COMMUNITIES

The sensitivity of a community is its ability to withstand and recover from disturbance. Some rocky shore communities are naturally unstable. This may be due to frequent physical disturbance. For example, chalk shores of the South Wight Maritime are unstable due to natural erosion. The rapid rate of erosion frequently exposes bedrock and prevents the development of stable, ‘mature’ communities. On such shores, additional low level impacts may make little difference to natural variability in species numbers and abundance. In many cases, natural instability results from a combination of stochastic events and intense biological interaction. These communities are particularly at risk from anthropogenic disturbance which could easily swing the balance in favour of one species or further destabilise the community.

The aftermath of oil spills demonstrates the vulnerability of rocky shore communities to acute impacts. Chemical dispersants and mechanical cleaning can do even more damage to the community than the oil itself. In many cases, the best course of action when spilt oil reaches a shore will be to leave it to disperse naturally. While rocky shores can recover from extensive acute impacts, this process takes a considerable time on a scale of tens of years when large stretches of coast are affected.

Localised disturbance to rocky shore communities will be caused by dumping or building on the shore. The local hydrodynamic regime and the degree of wave action experienced by the shore may be affected by developments, including moorings, further out to sea. A rigorous monitoring programme should be employed to detect the potential impacts of any new development.

Acute impacts are more easily detected and better studied than the more subtle effects of chronic factors. However, research did allow the adverse effects of TBT to be characterised and led to legislative changes. This illustrates the importance of research. The use of Ivermectin on fish farms is currently a cause for concern. Any expansion in the use of this chemical should be accompanied by targeted research to assess its impact on marine invertebrates and its ultimate effect on communities. The recreational use of shores has been shown to have negative effects on the shore community. Research is strongly encouraged, especially within SACs to investigate ways of minimising this impact without severely restricting public enjoyment of the shore. The presence of rubbish on the shore reduces its aesthetic appeal. Any objects which are heavy enough to smash encrusting organisms might result in increased physical disturbance to the shore community.

Although *Sargassum muticum* and *Elminius modestus* appear to have fitted into UK rocky shore communities without causing severe disruption, introduced species present a real threat. *Undaria* may prove to be a more damaging invader if it gets a foothold in the UK. Introduced species will have a severe impact when they displace other species. This could result in the local extinction of the displaced species. Global extinctions are unlikely as the various physical factors which affect rocky shores would be expected to check and limit the spread of the invader. Serious community level repercussions could occur if the displaced species provides microhabitats for other species or if it plays a key role in structuring the community.

D. PRACTICAL ISSUES

1. *Recreational impact versus public enjoyment.*

In the above sections we have highlighted the value of rocky shores as a public amenity for recreation and education, and the damage that visitors can cause. Educational field trips may increase this impact through samples collection and localised trampling. Easy public access lends conservation value to rocky shores. Ways should be found to minimise disturbance without unduly restricting such access, especially in SACs. Increasing public awareness may significantly reduce impacts of visitors, through promotion of positive behaviour (Chan, 1970). Hawkins and Jones (1992) list guidelines to minimise damage inflicted during field trips. A programme of public education could involve signs explaining the conservation significance of the site or a visitor centre (Fletcher, 1997), which may result in increased support for the SAC. It may also be necessary to encourage the public to limit their use of the shore to designated areas. Some site-specific research into the effects of visitors may be necessary.

2. *Monitoring programmes.*

Rocky shores are generally accessible, can be surveyed rapidly and are well understood. Techniques involve low-cost equipment and give the potential for rapid collection of quantitative or semi-quantitative data. Site visits are, however, time-consuming and necessarily limited to the daytime low tide periods of just a few hours each day. Consequently the choice of sites and the data collected need to be made maximally effective. We believe that this can be best achieved by careful consideration of the design of the survey in relation to the question asked, with a statistical hypothesis-testing rationale as the main underpinning for the adopted scheme. Estimation of abundance or cover estimates should be made for the main space-occupying (algae, barnacles, mussels), abundant structuring organisms (grazers, predators), and other species identified as important indicators of community type and environmental impacts. It matters less that abundance or cover data is collected in a rapid semi-quantitative way than that the sites and stations at which data are collected are chosen effectively. Assignment of a shore community to a biotope should not necessarily be the final aim of shore surveys, despite the attractiveness of the concept from a management viewpoint.

3. *Recovery*

Long term studies following the *Torrey Canyon* oil spill demonstrate that rocky shore communities can recover. The length of time this takes depends on the scale of the disturbance. The extent of any recovery should be assessed by reference to baseline data wherever possible.

a) No Intervention

In many cases, shore communities will recover best without human intervention and any post-impact management will often consist of monitoring this recovery. Some exceptions in which additional measures may aid recovery are discussed below. The *Torrey Canyon* incident illustrates that attempts to intervene can backfire. The consequences of any measures should be carefully assessed before they are widely used.

b) Removal of Litter

If the shore is badly affected by litter or debris, the only solution is physical removal of the offending material. Mechanical methods should be avoided as these may cause physical disturbance to the biological community. Removal by hand is labour intensive but often effective. The Marine Conservation Society successfully organises beach clean ups using a volunteer workforce.

c) Invading species

Communities may never naturally recover from invasion by an introduced species. The extent of the impact of a species on biodiversity will depend on several factors (Section IV.F, p48). Measures to control the spread of particularly damaging species might be the only way to conserve threatened communities. Many chemical and biological methods have been used in attempts to control ‘pest’ species. These control methods have had varying degrees of success and often cause severe ecological consequences. The development of safe and effective methods of control needs further research.

d) Recolonization

Some rocky shore species, such as dogwhelks, do not have a planktonic dispersal phase and are slow to recolonize sites after disturbance. Recolonization may occur only after adult individuals are transported to the shore by floating debris, for example. Reintroductions may be attempted from nearby populations to speed up the natural process. Some considerations need to be addressed before mass transplantation. Populations of such species are often adapted to their home shore. Dogwhelks from an exposed shore have low shells with large apertures which help them to withstand wave action but make them vulnerable to predation by crabs which are more numerous on sheltered shores. The ability of a population to survive in a particular area depends on the existing community in that area, not least its prey species.

E. THE STUDY AND MANAGEMENT OF ROCKY SHORES WITHIN SACs

In theory, rocky shores are an accessible, easily sampled marine habitat. Monitoring rocky shore communities is an efficient means of assessing the general condition of coastal ecosystems. Monitoring changes in the geographical ranges of rocky shore species would allow an assessment of the ecological consequences of climate change. There are certain features of individual shores which affect their suitability as monitoring sites. These are discussed below.

Accessibility. Rapid, efficient sampling of a site depends on ease of access. For obvious reasons, there will be considerable problems associated with sampling offshore sites such as Papa Stour and St Kilda and any other sites with no road access. Similarly, steeply sloping shores and cliffs are not suitable for rapid sampling.

Complexity. Most ecological studies of rocky shores have focused on free-draining bedrock. The communities present on this substratum are well understood and clearly defined sampling methods have been developed. Communities found in microhabitats such as crevices, rock pools and the underside of boulders are of considerable ecological interest but are less easily sampled. Monitoring programmes aimed at assessing impacts or the general condition of ecosystems should concentrate on free-draining bedrock. This will facilitate between site comparisons. Detailed studies of the ecological characteristics of shores should include microhabitats.

Representation. The value of rocky shore monitoring as a means of assessing the condition of coastal ecosystems is, obviously, limited by the presence of rocky shores. Monitoring the distribution of rocky shore species within SACs will allow an assessment of the ecological effects of climate change. The detail of any resulting data will be limited by the number and distribution of monitoring sites. South Wight Maritime may prove a useful site for monitoring the eastern spread of Atlantic species. However, not all species will establish populations on this unstable shore. Changes in the Northern or Southern limits of species will be best seen along the West coast. We recommend that any attempt to initiate a programme to monitor the effects of climate change should integrate additional West Coast sites with those in SACs. Ideally, these would be situated within easy working distance of marine research centres.

F. GENERAL IMPLICATIONS FOR MANAGEMENT OF SACS

Where suitable rocky shores exist within SACs, we suggest that these are used as a basis for monitoring the condition of coastal ecosystems and assessing the impact of anthropogenic activities. We also recommend the initiation an integrated programme to monitor the effects of climate change on the distribution of rocky shore species. This programme should involve all SACs which adopt rocky shore monitoring and, possibly, additional West Coast sites. Monitoring of rocky shores can be based on simple techniques involving in-situ assessment of the abundance of up to 30 species. This work must be conducted by field workers who understand the sampling scheme and are skilled at identifying the relevant species. Since rocky shore monitoring clearly has a significant role to play in the management of SACs, we recommend that training should be made available on a national basis to ensure that practitioners have these skills and that practices are standardised.

Rocky shores are susceptible to acute and chronic anthropogenic impacts. The conservation objectives of SACs can be met if potential impacts are identified and minimised. The identification of chronic impacts will depend on well designed surveillance programmes. A particularly important issue is the potential effect of visitor pressure. We recommend the implementation of programmes which both minimise this impact and cultivate public goodwill and understanding of conservation issues. On site education will partially fulfil these needs. However, specific strategies, based on local research, should be devised to protect popular shores.In general, shores which have suffered anthropogenic disturbance are best left to recover without any human intervention. The main exception is that shores soiled with rubbish should be cleared by hand. It might be possible to achieve this with a volunteer workforce who should be well briefed to prevent any further disturbance.

G. KEY POINTS

- The main conservation value of rocky shores lies in their accessibility. They are of considerable amenity value for both recreation and education. They can also be easily and efficiently surveyed.
- Monitoring of rocky shore communities is recommended to assess anthropogenic impacts and the general condition of coastal ecosystems.
- Many littoral species reach their geographical limits on British shores. Therefore, the ecological consequences of climate change could be monitored through an integrated programme involving SACs and, possibly, other sites.
- Because they are accessible to the public, rocky shores can be used to promote the conservation objectives of marine SACs.
- Visitor pressure can cause a significant impact on rocky shore communities. Public education is recommended as a strategy to minimise this impact.
- Rocky shores communities will recover naturally from anthropogenic impacts. The rate of recovery depends on the scale of the impact. Attempts to intervene after an impact have usually proved disastrous in the past.

IX.

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Appendix 1. MNCR BioMar biotope classification - Intertidal reef types assessed for stability

Higher code	Biotope Code	Stability	Key References
LR			
LR.L	YG	STABLE	
LR.L	Pra	Seasonally variable	Hawkins and Hartnoll, 1983
LR.L	Ver	STABLE	
LR.L	Ver.Por	*Porphyra* fluctuates seasonally	
LR.L	Ver.B	Stable	
LR.L	Ver.Ver	Stable	
LR.L	Chr	Seasonally variable	
LR.L	Bli	Seasonally variable	
LR.L	UloUro	Stable, can die off if dried out in summer	
ELR			
ELR.MB	MytB	Locally unstable, but assemblage persistent at 100m-km scale	Lewis, 1976, 1977
ELR.MB	Bpat	Generally stable, occasional escapes of fucoids	Southward and Southward, 1978
ELR.MB	Bpat.Cht	STABLE	Connell and Sousa, 1983
ELR.MB	Bpat.Lic	STABLE	
ELR.MB	Bpat.Cat	STABLE	
ELR.MB	Bpat.Fvesl	Some local instability but mosaic persistent on larger scale	
ELR.MB	Bpat.Sem	Stable, but occasional *Fucus* escapes on horizontals	
ELR.FR		Stable but rare (Scotland and Ireland only)	Powell, 1957
ELR.FR	Fdis		
ELR.FR	Coff	STABLE - occasional small scale disturbance events	
ELR.FR	Him	Can fluctuate seasonally with the growth of *Himanthalia. Himanthalia* also varies between years	
MLR			
MLR.BF			
MLR.BF	PelB	Stable, but *Pelvetia* can suffer from occasional hot summers	Schonbeck and Norton, 1978 Hawkins and Hartnoll, 1985
MLR.BF	FvesB		
MLR.BF	Fser	Locally very variable, can swing to barnacles only	
MLR.BF	Fser.R	Generally stable. Cover fluctuates seasonally, but not much year to year variation	Hawkins and Hartnoll, 1983
MLR.BF	Fser.Fser	as Fser.R	
MLR.BF	Fser.Fser.Bo	as Fser.R	
MLR.BF	Fser.Pid	Piddocks vulnerable to cold water extremes	Crisp, 1964

Appendix 1. MNCR BioMar biotope classification - Intertidal reef types assessed for stability

Higher code	Biotope Code	Stability	Key References
MLR.R			
MLR.R	XR	Stable at functional group level, but individual species fluctuate a lot	
MLR.R	Pal	Can fluctuate a lot. *Palmaria* colonizes disturbed areas	Hawkins and Harkin, 1985
MLR.R	Mas	Stable	
MLR.R	Osm	Patches stable	
MLR.R	RPid	Piddocks vulnerable to cold water extremes	
MLR.Eph			
MLR.Eph	Ent	Seasonally unstable, unstable in the longer term	
MLR.Eph	EntPor	Very unstable, seasonal fluctuations	Hawkins and Hartnoll, 1983
MLR.Eph	Rho	Quite stable	
MLR.MF			
MLR.MF	MytFves	Localised dynamic patches	
MLR.MF	MytFR	Moderately stable	
MLR.MF	MytPid	Unknown	
MLR.Sab		[NB: MLR.Sab is not within the remit of this Review]	
MLR.Sab	Salv	Fluctuate, individual reefs unstable with a 3-4 year turnover. Reef positions may move.	
SLR			
SLR.F	Pel	STABLE	
SLR.F	Fspi	STABLE	
SLR.F	Fves	STABLE	
SLR.F	Asc	Very STABLE	
SLR.F	Asc.Asc	Very STABLE	
SLR.F	Asc.T	STABLE	
SLR.F	Asc.VS	Unknown	
SLR.F	Fserr		
SLR.F	Fserr.T	Seasonal fluctuations, moderately stable	
SLR.F	Fserr.VS	Moderately stable	
SLR.F	Fcer	Stable	
SLR.FX			
SLR.FX	BLlitt	Unstable	
SLR.FX	FvesX	Stability of the community depends on the stability of the substratum	
SLR.FX	AscX	As FvesX	
SLR.FX	AscX.mac	As FvesX	
SLR.FX	FserX	As FvesX	

Appendix 1. MNCR BioMar biotope classification - Intertidal reef types assessed for stability

Higher code	Biotope Code	Stability	Key References
SLR.FX	FserX.T	Moderately stable. All *F. serratus* biotopes tend to show seasonal patterns	
SLR.FX	EphX	Highly variable	
SLR.FX	FcerX	Unstable	
SLR.MX			
SLR.MX	MytX	Locally unstable, but predictable on a wider scale	
LR.Rkp			
LR.Rkp	G	Seasonally variable	
LR.Rkp	Cor	STABLE	
LR.Rkp	Cor.Par		
LR.Rkp	Cor.Bif	STABLE	
LR.Rkp	Cor.Cys		
LR.Rkp	FK	STABLE	
LR.Rkp	FK.Sar	Seasonal fluctuations	
LR.Rkp	SwSed	Variable/Unstable	
LR.Rkp	H	Variable/Unstable	
LR.Ov			
LR.Ov	RhoCv	Stable	
LR.Ov	SR	Stable	
LR.Ov	SByAs	Stable	
		Note: *Cladophora rupestris* assemblages can be very stable	
Comments on other types			
EIR			
EIR.KFaR	Ala	Local disturbance by storms but rapid recolonization	
EIR.KFaR	Ala.Myt		
EIR.KFaR	Ala.Ldig	Some variability - *Alaria* colonizes disturbance patches	
MIR.KR			
MIR.KR	Ldig	Stable	
MIR.KR	Ldig.Ldig	Stable	
MIR.KR	Ldig.Ldig.Bo	Stable	
MIR.KR	Ldig.T	Stable	
MIR.KR	Ldig.Pid	Stable	
SIR.K	Lhyp.L.sac	*Laminaria saccharina* shows annual fluctuations	