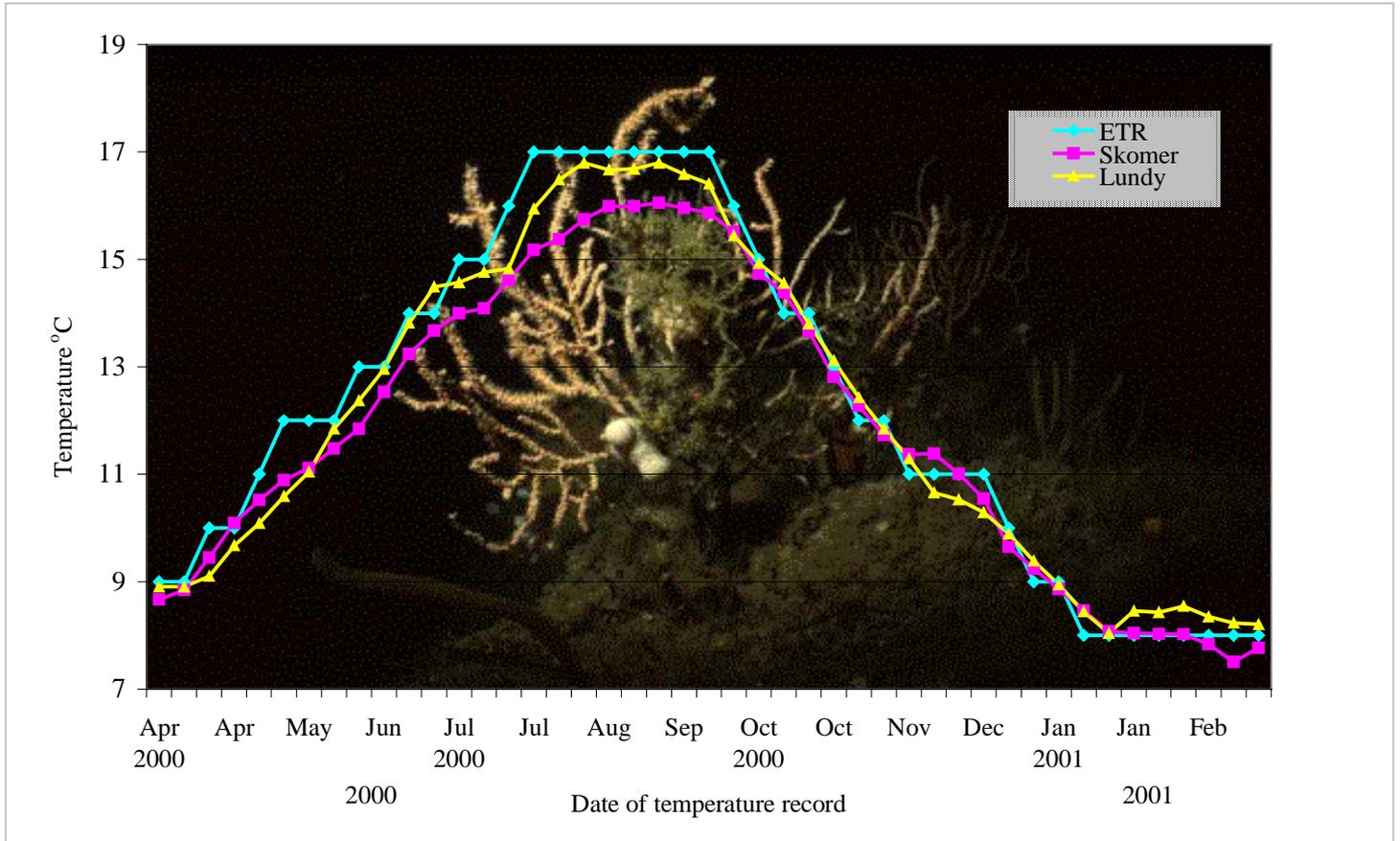


Reef Research

CLIMATE CHANGE IMPACTS ON SEAFAN POPULATIONS



A Report by Reef Research (UK)

PREPARED WITH FINANCIAL ASSISTANCE
FROM ENGLISH NATURE



June 2003

Reef Research

E-mail: enquiries@reef-research.org

Web Site: <http://www.reef-research.org>

Contact: Colin & Lexie Munro, Project Directors

Climate change impacts on seafan populations

April 2003

REEF RESEARCH

*1 Orchard Cottages, Coombe Barton
Shobrooke, Crediton, Devon EX17 1BS
Tel/Fax +44 (01) 363 775278 Mobile 07977 096738
E-mail: enquiries@reef-research.org
Web Site: <http://www.reef-research.org>
Contact: Colin & Lexie Munro, Project Directors*

Report by:

Lexie Munro & Colin Munro

Report Ref: RR Report 6/2003 RR 08

“Currently the most relevant physical and temporal scales of ecological investigation are local and short -term (less than three decades). In contrast, climatology generally encompasses much larger spatial and temporal scales. As a consequence it remains difficult to link population and community-level dynamics to the global-scale studies of atmospheric and oceanic processes.”

Walther, (2002)

Contents

Summary	1
1. Introduction	3
2. Gorgonian sensitivity to temperature	3
2.1 Narrow temperature tolerance of adult colonies	4
2.1.1 <i>Spawning and temperature</i>	4
2.1.2 <i>Upper temperature threshold</i>	5
2.1.2.1 Spatial distribution of temperate gorgonians	5
2.1.2.2 Mechanisms of temperature stress	6
2.1.2.2.1 Physiological stress	6
2.2 Survival and settlement of gorgonian larvae	11
2.2.1 <i>Key aspects of gorgonian larval ecology</i>	11
2.2.2 <i>Larval settlement</i>	12
2.2.3 <i>Larval survival</i>	12
2.2.4 <i>Larval distribution</i>	13
3. Monitoring temperate reef species in relation to climate change	13
3.1 Existing UK monitoring requirements for temperate reef species in relation to climate change	13
3.1.1 UK Biodiversity Group's Species Action Plan (SAP)	13
3.1.2 UK Marine Special Areas of Conservation (SAC's) Project	14
3.2 Achieving SAC and SAP requirements	14
3.2.1 What needs monitoring	14
3.2.2 What is being monitored	14
3.2.2.1 Baseline data on UK seafan population distribution	14
3.2.2.2 Long term population monitoring	15
3.2.2.3 Physical data collection	15
3.2.2.3.1 Seabed and sea surface temperature data	15
3.2.2.3.2 Use (& misuse) of SST in predictions of marine temperature change	17
3.2.2.3.3 Existing seabed temperature data	17
3.2.2.3.4 Limitations of existing seabed temperature data	20
4. Use of seabed temperature data in relation to benthic community monitoring programmes	21
4.1 Links between physical data collection and rationale for biotic monitoring	21
4.2 Lack of physical data collection to support monitoring of the biota	21
4.3 Examples of biotic response to extreme change in physical environment	21
4.4 Case example of an established sea temperature monitoring programme	23
5. Recommendations for further research and monitoring	25
4.1 Research	25
References	27
Appendix 1	30
Appendix 2	33

Summary

Research into the effects of climate change on tropical corals has not been matched by research in temperate reef communities. The likely effects of climate change on UK gorgonian populations is considered using 1) broad evidence of the response of other gorgonian species to temperature increases and 2) limited data on the ecology of *Eunicella verrucosa*, to predict the species' potential response to changes in temperature.

Temperature is thought to be an important factor in determining the distribution of gorgonian populations. Several gorgonian species require water temperatures to rise above a certain threshold as a cue for spawning, yet appear to have a lethal upper temperature only a few degrees higher. The physiological mechanism underpinning temperature tolerances of gorgonians is poorly understood. There is growing evidence of a positive correlation between diseases in gorgonians and elevated water temperatures. Under higher than average water temperatures corals may become stressed and / or show a reduced resistance to disease. Some gorgonian diseases may be more virulent at higher temperatures.

It is believed that the geographical limits of *Eunicella verrucosa*'s distribution are, to some extent, temperature dependent. Early research suggests a possible correlation between peak water temperature and annual spawning in *Eunicella verrucosa*. To our knowledge there has been no research into *Eunicella verrucosa*'s physiological response to temperature stress, or of the species which are potential pathogens to UK gorgonian populations.

The early life history and reproductive strategy of gorgonians is highly variable between species. Reproduction can be sexual or asexual. In species which reproduce sexually, fertilisation may be external (through broadcast spawning) or internal, with subsequent brooding of larvae. Once released, planulae larvae do not always undergo a planktonic phase. It is anticipated that future increases in water temperature & alterations in major current systems will influence larval survival, distribution and settlement. It is impossible to predict the likely extent of effects at the larval stage without better understanding of gorgonian larval ecology.

We currently believe that *Eunicella verrucosa* reproduces sexually, but it is not known how gametes are fertilised. To date no research has considered the species' larval ecology.

Existing guidance for the management of UK seafan populations highlights the need for detailed monitoring to reveal any changes in species' distribution in relation to long-term climate change. To achieve this we need an understanding of the current distribution of UK seafan populations coupled with baseline data on the species population dynamics (including factors affecting recruitment & survival and "natural" levels of spatial and temporal population change). Recent research programmes have helped advance our understanding of seafan distribution and ecology. Such programmes need to be sustained in the long-term to generate scientifically robust data.

To implement relevant management guidance for sublittoral reef species it is necessary to record both physical and biological data from reef environments. Temperature monitoring is particularly relevant for determining the effects of climate change. In the UK regular Sea Surface Temperature (SST) monitoring is conducted by the Environment Agency. Most predictions of temperature change in the marine environment are based on models utilising SST data. However it is inappropriate to infer seabed water temperatures from temperature data collected from surface waters. *In situ* seabed temperature monitoring is essential to determine the physical environment of reef habitats, and detect any changes therein. Recent programmes to monitor the temperature of seabed waters around the UK have been limited to three point sites collecting continuous data (Skomer, East Tennants Reef and Lundy). Data overlap between all three sites occurs over just one 11-month period. Ongoing seabed temperature monitoring is currently conducted at just two sites; Skomer and East Tennants Reef. Temperature data has also been collected around Lundy but a monitoring programme still needs to be established there.

A range of programmes have been set up in the UK to monitor the biota of benthic communities. One of the primary reasons for monitoring biotic communities is to detect cycles, shifts in equilibrium, or trends which may be linked to other physical or biotic changes. However, **correlations between physical and biotic events can only be drawn with confidence if the physical conditions likely to influence community structure have also been monitored.** The current level of seabed temperature monitoring is inadequate to support biotic data for the majority of benthic marine monitoring projects.

In recent years there have been numerous mass mortality events affecting gorgonian communities (e.g. in the Florida Keys, across the Caribbean and in the NW Mediterranean). Assessments of the causes and effects mass mortality events have been facilitated where extensive pre and post mortality data has been available to describe both physical and biological environments.

A decline in the extent and condition of marine invertebrate species (including gorgonian populations) around Lundy has recently been observed. Scientific interpretation of this event is restricted by lack of data on the island's physical marine environment.

Worldwide, there is increasing awareness of the need to consider the physical and biological condition of marine communities in order to monitor change. An Australian sea temperature monitoring programme illustrates the kind of programme which can be set up to record extensive temperature data. The implementation of a similar programme to record seabed temperatures around the UK is long overdue & is considered essential to monitoring the response of sublittoral communities to future climate change.

Recommendations are made for further research and monitoring to improve our current understanding of the ecology of temperate reef species & the physical environment of UK sublittoral reefs.

1. Introduction

In recent years there has been growing interest in the effects of climate change on tropical coral reefs. Recent research has generated evidence of links between increased seawater temperatures and the occurrence of mass mortality events, coral bleaching episodes & disease outbreaks among tropical corals (e.g. Harvell *et al.*, 2001; CRC Reef Research Centre, 2003; Goreau, 2003). There is now an increased research emphasis on improving understanding of the physiological mechanisms underlying the response of tropical corals to temperature stress (e.g. Acosta, 2001; Harvell *et al.*, 2002; Kim *et al.*, 2000). It has also become widely accepted that detailed monitoring of both physical and biological parameters is needed to identify population and community level changes in response to seawater temperature change (CRC Reef Research Centre, 2003; Walther *et al.*, 2002).

The effects of climate change on temperate reef communities remain poorly understood. It is expected that changes in temperature and hydrographical regimes will result in changes in the distribution of many north eastern Atlantic and Mediterranean epibenthic species; some predictions have already been made as to the nature of these changes (e.g. UK Marine SAC's project, 2003; Hiscock *et al.*, 2001). Such distribution changes are likely to have profound implications for marine monitoring and national/regional marine biodiversity strategies. Guidance on the monitoring of UK marine Special Areas of Conservation highlights the need to track the response of sublittoral communities to climate change (UK marine SAC's project, 2003). However, this requirement cannot be achieved unless a better understanding is developed of both the ecological requirements of the constituent species and the physiological mechanisms underlying temperature sensitivity. Moreover, we cannot correlate changes in species or communities with changes in temperature without collecting local physical data.

This paper considers the potential impacts of climate change on UK populations of seafans. We draw on the known temperature responses of other gorgonian species and the results of our own research into the ecology of *Eunicella verrucosa*, to suggest potential temperature sensitivity of UK seafan populations. We also outline the current UK monitoring requirements for reef species in relation to temperature change, and summarise existing seawater temperature data sets. The use of this data in relation to benthic community monitoring programmes is considered. Finally we recommend areas where we believe further research and monitoring should be targeted.

2. Gorgonian sensitivity to temperature

Temperature is believed to be a determining factor for the distribution of many temperate-water gorgonian species. Gorgonian sensitivity to temperature is probably due to the following

- A narrow temperature tolerance of adult colonies
- Influences of temperature on the survival and settlement of gorgonian larvae

2.1 Narrow temperature tolerance of adult colonies

Several gorgonian species require water temperatures to rise above a certain threshold as a cue for spawning, yet appear to have a lethal upper temperature only a few degrees higher. This suggests that such populations remain viable only within a within a narrow range of temperatures.

2.1.1 Spawning and temperature

Studies of reproduction in temperate gorgonian species have suggested that spawning is triggered by a combination of environmental cues. Water temperature is thought to be one of the most influential factors in the synchronisation of spawning events. It remains unclear whether an increase in water temperature initiates spawning or is necessary for the final stages of gametogenesis (Grigg, 1977). Studies of temperate gorgonian species in which spawning has been found to coincide with increased water temperature include:

- Preliminary studies of reproduction in Skomer and Lyme Bay populations of *Eunicella verrucosa* suggest that release of gametes may occur in late August to early September (Munro & Munro 2003). As shown in Figure 1, the proposed time of spawning coincides with peak water temperature for both Lyme Bay and Skomer populations.

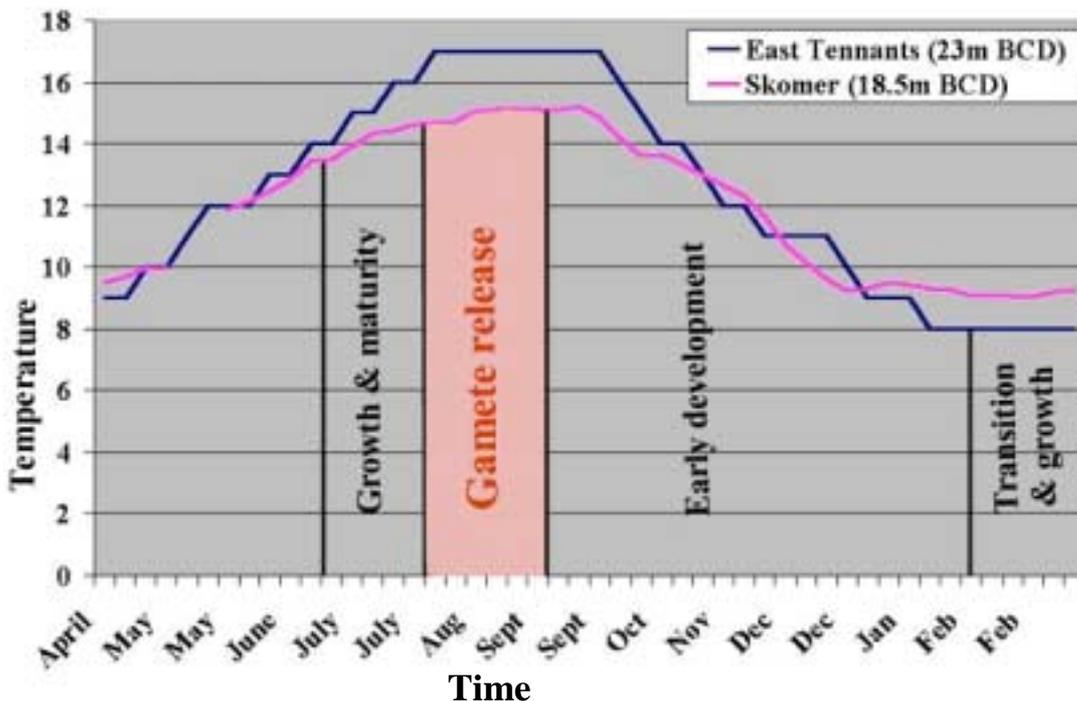


Figure 1 Summary of the phases of reproductive maturity in *Eunicella verrucosa* populations at Skomer, West Wales and East Tennants Reef, Lyme Bay. Reproductive phases (observed 2002 – 2003) are presented against seabed temperature data collected at Skomer MNR (2001-2002) and East Tennants Reef (2000 – 2001). *Skomer temperature data provided by CCW, Skomer.*

- Grigg (1977) found that two Californian gorgonian species (*Muricea californica* and *Muricea fruticosa*) each spawn once a year, at a time corresponding to annual peak water temperature. In both species colonies occurring in shallow water spawned before deeper colonies. It was suggested that a lag in the occurrence of peak water temperature at depth causes a delay in the spawning of deeper colonies.
- Weinberg & Weinberg (1979) observed a similar effect in Mediterranean populations of the gorgonian *Eunicella singularis* with colonies occurring in shallower, warmer waters spawning earlier in the season than those found in deeper, colder waters.
- Coma et al. (1995) observed that, over three separate years spawning in *Paramuricea clavata* coincided with a “marked increase in water temperature”.

2.1.2 Upper temperature threshold

2.1.2.1 Spatial distribution of temperate gorgonians

The geographic and depth zone distribution of many temperate water gorgonian species appears to correlate with isotherms delineating temperature maxima and minima. This suggests that for many species, temperature tolerance is a key limiting factor. However this is based on geographical and depth correlations with temperature, rather than direct evidence of a physiological response to high or low temperatures. Some examples of studies linking gorgonian distribution with water temperature are given below. In considering this evidence it is important to bear in mind that the existence of a correlation does not imply a direct cause and effect relationship

The following examples illustrate gorgonian species whose spatial distribution has been linked with water temperature

- The pink seafan, *Eunicella verrucosa* is frequently found in waters of less than 20 metres chart datum around Southern U.K. In the Alboran Sea off Southern Spain, where peak summer sea surface temperatures are several degrees higher than those of SW Britain, it occurs at around 30m and deeper. Off north-eastern Spain, where summer peak water temperatures are some 2-4°C higher still, *E. verrucosa* is rarely found shallower than 50m (Rafel Coma and Marta Ribes, pers. comm.).
- Within the western Mediterranean, the seafan *Eunicella singularis* occupies the depth zone immediately shallower (and warmer) than *E. verrucosa*, and its range does not extend as far North in the Atlantic.
- The seafan *Swiftia pallida* (often described, rather inappropriately as the northern seafan in the UK) occurs from Scandinavia South to at least Morocco and throughout the Mediterranean. However, only in the northern parts of its range, Scotland to Norway, is it found in depths shallow enough to be encountered by most SCUBA divers (i.e. less than 50m). Within the Mediterranean it is rarely found shallower than 100m, and most common between 400-600m.

- Harmelin (1994) suggested that the exclusion of gorgonians from the Eastern Mediterranean basin is most likely due to the higher sea water temperatures of that region (as compared with the Western basin).
- Garrabou *et al* (2001) hypothesise that the absence of *Corallium rubrum* (red coral) from the Eastern Mediterranean may indicate an inability for the species to survive in “an environmental context of high seawater temperatures”.
- In a study of the autoecology of Mediterranean octocorals (including four gorgonian species) Weinberg, (1979) concluded “each species has its own requirement regarding... water temperature & submarine daylight”. He suggested that temperature excludes *Eunicella singularis* from locations where average summer water temperature is greater than 20.1 °C. *Lophogorgia ceratophyta* was found to be fairly tolerant of range of light & temperatures as was *Paramuricea clavata*, while *Corallium rubrum* was found exclusively in cooler darker stations. (Weinberg’s study highlights the difficulty of distinguishing between temperature, irradiance and depth as factors which determine sublittoral spatial distributions).

2.1.2.2 Mechanisms of temperature stress

There is some evidence of stress / mortality amongst temperate gorgonian corals in response to temperatures rising above optimal levels. As an example in 1973 mortality of *Eunicella singularis* colonies occurred at Banyuls-sur Mer following abnormal heating of the water layer above the thermocline to 24°C (Weinberg, 1979). The mechanism underlying temperature-related stress is still poorly understood for temperate gorgonian species. It seems likely that increased water temperatures result in 1) increased physiological stress and / or 2) increased susceptibility to disease.

2.1.2.2.1 Physiological stress

There has been very little research into the physiological response of gorgonians to increases in water temperature. We are aware of only one study (Coma *et al.*, 2002) aimed at monitoring physiological parameters in relation to changing water temperature. The study noted that a period of dormancy (characterised by lowered respiration rates & reduced synthesis of new tissue) occurred during the period of highest water temperature. It was suggested that energy limitations underlie summer dormancy.

Other researchers have made speculative suggestions on the likely physiological responses to temperature stress. For example Garrabou *et al.* (2001) suggested that an anomalous increase in seawater temperature in the Western Mediterranean (about 6°C increase at 20m depth during late summer 1999) could have led to physiological stress in *Corallium rubrum*.

To date there is no information on the physiological response of *Eunicella verrucosa* to increases in water temperature.

2.1.2.2.2 Increased susceptibility to disease.

There is growing evidence of a link between the incidence of coral disease and increased environmental stress (for example through elevated water temperature,

sedimentation or an increase in pollutants) (Kim *et al* 2000). The mechanisms by which the incidence of coral disease correlates with increased water temperature can be broadly divided into a) host-related and b) pathogen-related effects.

In this section we review evidence from studies of both tropical and temperate gorgonian species to highlight potential mechanisms through which the incidence of coral diseases may be linked to water temperature.

a) Host related effects

High energetic costs of repairing damaged tissue

One of the most commonly observed effects of disease in gorgonian corals is the loss of coenchyme tissue, leaving an exposed axis which is susceptible to fouling by epibionts (Bonhomme *et al.* 2003, Nagelkerken *et al.*, 1997; Harmelin, 1994). In a study of damaged *Corallium rubrum* colonies the highest mortality rates were observed amongst small colonies and / or larger colonies with extensive areas of damage (Garrabou *et al.* 2001). It was suggested that small and heavily damaged colonies have insufficient energetic resources to effect tissue repair and / or successfully compete with epibionts for resources.



Figure 2 Showing the same *Eunicella verrucosa* colony photographed in August 2000 (left) and April 2001. By April 2001 coenchyme tissue loss & growth of epibionts is evident in the upper branches of the colony (arrowed). *Images from Reef Research time-series monitoring data.*

Long-term photo-monitoring of *Eunicella verrucosa* colonies suggests that epibiosis frequently occurs on areas of the colony where coenchyme has been lost (see Figure 2). To date there has been no study of the success of epibiotic colonisation in relation to water temperature.

Depletion of available energy resources following expulsion of algal symbionts

Metabolically stressed corals are believed to be more susceptible to outbreaks of disease than healthy corals (Acosta, 2001). Numerous studies have proposed tentative links between increased water temperature and ‘stress-facilitated disease’ (see for example Harvell *et al*, 2001; Acosta, 2001). It is well recognised that many tropical coral species respond to small increases in water temperatures by expelling their algal symbionts in episodes of “coral bleaching” (CRC Reef Research Centre 2003). It is thought that as a result of bleaching corals are unable to feed photoautotrophically and thus cannot generate sufficient energy to maintain basic metabolic processes. While many coral reef octocorals are thought to have zooxanthellate algal symbionts, azooxanthellate species are also known to occur in deeper water (Richmond, 1997). It is not known whether zooxanthellae are associated with temperate gorgonian species. Without knowledge of temperate gorgonian / zooxanthellae relationships, it is impossible to determine whether metabolic stress resulting from symbiont expulsion is likely to influence potential temperature responses of UK gorgonian populations.

Decreased defence potential

Many gorgonians are known to rely on secondary chemicals as defence against disease and predation. Details of numerous studies which have considered secondary chemicals produced by gorgonians as anti-bacterial & anti-fungal compounds can be found in Dube *et al* (2002). There is evidence that some defence compounds used by gorgonian corals become less effective with increased temperature. Harvell *et al*, (2001) for example refer to decreased efficacy of seafan extracts at 30°C relative to 25°C.

To date there has been no research into the chemical defence systems of *Eunicella verrucosa*.

Population level effects

There are several aspects of gorgonian ecology which may contribute to population level effects following outbreaks of disease, as outlined in Table 1. For most species reliable data on gorgonian population dynamics is lacking, making it difficult to predict population level effects. Predictions (based on limited population ecology data) suggest that recovery of gorgonian populations from mass mortality events is likely to occur on a scale of decades rather than years (Bonhomme *et al*, 2003). In association with the 1998 El Niño–Southern Oscillation event, severe coral bleaching / mortality was observed worldwide (Harvell *et al* 2002). Numerous studies have subsequently been set up to consider temperature related coral mortality and population recovery, but their research span is at most five years to date (see for example Garrabou *et al* 2001; Harvell *et al*, 2001; Bonhomme *et al*, 2003). The generation of realistic information on the recovery of gorgonian populations from disease outbreaks is likely to require population studies of a duration >5 years.

The majority of research into the population ecology of *Eunicella verrucosa* has been conducted over the past five years by Reef Research. Information and publications detailing growth rates, recruitment & mortality levels, reproductive biology, fecundity and age-specific survivorship of South western *E. verrucosa* populations are available

Table 1 Showing the aspects of gorgonian ecology which may contribute to population level effects following the outbreak of disease

Ecological / life history attribute	Potential effect at population level
<p><i>Gorgonians are colonial organisms their reproductive capacity and potential for population growth is positively correlated to the amount of total living tissue</i></p> <p>The number of polyps increases exponentially with colony size</p>	<p>Diseases which causes the loss of reproductively mature polyps are likely to lead to reduced fecundity (at both individual and population levels).</p> <p>In the short term loss of polyps may cause a negative trend in overall population growth while the long term effects of colony damage may be a negative shift in population size structure.</p>
<p>Synchronised spawning events occur on an annual basis</p> <p>Spawning is preceded by a long period of gametogenesis, usually lasting several months (Munro & Munro, 2003)</p>	<p>Annual disease outbreaks will impact on every reproductive event – either at spawning or gametogenesis</p> <p>Reduced recruitment capacity may cause slow population recovery</p>
<p>Energy allocated to reproduction is done so at the expense of growth (Coma <i>et al</i>, 1995)</p>	<p>As a result of disease outbreaks energy may be diverted away from reproduction to maintenance, tissue regeneration and defence. Reproductive capacity of the population may be impacted</p>
<p>Tissue regeneration can be relatively slow & may incur high energetic costs (Garrabou <i>et al</i>, 2001)</p>	<p>Colonies suffering tissue damage as a result of disease may have insufficient energy resources to repair damage and / or compete with epibionts colonising damaged areas. This may result in the total death of colonies only partially damaged by disease.</p>
<p>Larval recruitment rates are generally low and variable between years (Munro & Munro, 2003)</p> <p>Low capacity for larval dispersal is common (Garrabou <i>et al</i>, 2001; (Brazeau & Lasker, 1989)</p>	<p>Recovery of populations may be limited by poor larval recruitment.</p> <p>Recruitment from adjacent non-impacted populations may not be possible</p>

via the Reef Research website (www.reef-research.org). As noted above, five years' data collection provides limited detail of gorgonian population ecology. It is intended that ongoing monitoring by *Reef Research* will facilitate improvements in the strength of our data.

b) Pathogen related effects

Improved pathogen survival at high temperatures

Since the growth and replication rates of many marine bacteria and fungi are positively correlated with temperature, it has been predicted that climate warming could improve the survival rates of tropical marine pathogens (Harvell *et al* 2001). As an example the occurrence of Black Band Disease (BBD) of scleractinian corals in the Florida Keys virtually disappears in the winter but is most active during the summer. The disease has an optimal temperature of between 28 – 30°C (Rutzler *et al* 1993 & Kuta & Richardson, 1996 in Harvell *et al* 2001).

In temperate waters increased pathogen virulence can also occur at higher water temperatures. For example the bacteria *Vibrio shiloi*, which causes bleaching of the Mediterranean stony coral *Oculina patagonica*, is more active at higher temperatures (Dicks, 2003).

For many corals the effects of improved pathogen survival at higher temperatures are thought to be amplified if host resistance is already compromised due to the metabolic stresses of an increased temperature regime (see section 2.1.2.2 above). For some pathogens optimal growth rates are known to occur at temperatures close to, or exceeding, their host's thermal optimum. As an example, *Aspergillus sydowii* has recently been identified as the fungal pathogen in the current outbreak of Aspergillosis in seafan populations across the Caribbean and Florida Keys. The disease is characterised by tissue necrosis / lesions, purpling of tissue, galls and tumours (Dube *et al* 2002). Optimal growth of *A. sydowii* occurs at 30°C – the typical temperature limit at which coral bleaching occurs.

We are not currently aware of any pathogens affecting UK populations of *Eunicella verrucosa*. There is some speculation that recent damage to populations of *E. verrucosa* around Lundy may be directly or indirectly linked to a microbial infection (Hiscock, pers. comm. 2003).

Pathogen range expansion

It is believed that bodies of cold water provide spatial and temporal barriers for the distribution of some marine pathogens. Increases in seawater temperature may remove cold-water barriers allowing certain pathogens to extend their range. As an example Harvell *et al* (2002) describe the geographic spread of Eastern Oyster disease *Perkinsus marinus* on the US east coast following the removal of a cold water barrier during a winter warming trend in the 1980's.

Currently there is little or no information on the types of pathogens affecting common benthic marine species found in UK waters (other than those affecting commercial species). Thus it is not possible to identify how such pathogens are currently distributed or to suggest how this might change in warmer waters.

2.2 Survival and settlement of gorgonian larvae

Changing seawater temperatures are thought likely to influence the distribution, survival and settlement of gorgonian larvae. These factors may contribute to changing the current range and population structure of UK gorgonian populations. To date there has been little research into gorgonian larval ecology. We are not aware of any case evidence of gorgonian larval responses to changes in water temperature. This section draws on a limited knowledge of gorgonian larval ecology to speculate on the potential effects of climate change for larval settlement, survival and distribution.

2.2.1 Key aspects of gorgonian larval ecology

Where research evidence is lacking, predictions relating to the reproductive strategy of individual species are complex, since gorgonians are known to employ a range of reproductive mechanisms. As summarised in Table 2, reproduction can be sexual or asexual, fertilisation can be internal or external, and planulae larvae may settle immediately or undergo a planktonic phase of variable duration. We currently believe that UK populations of *Eunicella verrucosa* reproduce sexually, but do not know whether larvae produced are planktonic, and if so, how long they spend in the water column (Munro & Munro, 2002).

Table 2 Showing the range of gorgonian reproductive strategies, providing examples of species using each strategy and outlining whether the strategy is thought to be employed by *Eunicella verrucosa*.

Reproductive strategy	Examples of gorgonian species using this strategy	<i>Eunicella verrucosa</i>
Planulae larvae produced but do not have planktonic phase	Spawned eggs adhere to mucus coating on female colonies & develop into planulae larvae which settle on the surrounding substrate immediately after detachment from female colonies (<i>Paramuricea clavata</i> , Coma <i>et al</i> , 1995).	Uncertain whether larval phase is planktonic.
Planulae larvae with planktonic phase	Planulae larvae released from polyps & begin to fall towards substrate due to their slightly greater density than seawater. Planktonic phase lasting from a few hours to a few days prior to settlement. (<i>Eunicella singularis</i> , Weinberg & Weinberg, 1979)	Uncertain whether larval phase is planktonic. Spawned gametes observed in water column for up to 48 hours during tank studies.
Asexual reproduction	Asexual reproduction by fragmentation (<i>Plexaura A</i> ; Brazeau & Lasker, 1989)	Unconfirmed possibility of asexual reproduction by fragmentation
Sexual reproduction	Production of gametes from gonads within the mesenteries (<i>Eunicella singularis</i> , Weinberg & Weinberg, 1979; <i>Paramuricea clavata</i> , Coma <i>et al</i> , 1995)	Evidence of gamete development indicates sexual reproduction occurs
Temperature cue for final stage of larval settlement	No known examples	Unknown - Larval phase largely unstudied.

2.2.2 Larval settlement

It has been suggested that for some species the final settlement stage of larval development may be triggered by temperature (See for example Hiscock *et al*, 2001; McCormick & Molony, 1995). Future increases in seawater temperature may result in larval recruitment at sites previously inaccessible for settlement due to an unsuitable temperature regime (Hiscock *et al*, 2001).

As shown in Table 2 the larval phase is largely unstudied amongst gorgonian species. It remains unknown whether the settlement stage of gorgonian larval development is temperature-dependent.

We currently have no understanding of *Eunicella verrucosa*'s larval ecology. It is therefore impossible to predict how the settlement of *Eunicella verrucosa* larvae will be affected by future increases in water temperature.

2.2.3 Larval survival

Research into larval survival and development rate suggests that, for some species, fluctuations in water temperature may therefore have a direct influence on larval survival. As an example Pennington *et al*, (2003) observed optimal development and survival of brachiopod larvae raised in water at temperatures of 15°C and 10°C. Abnormal settlement or death of larvae was observed at higher temperatures (20 and 25°C). At a lower temperature (5°C) larvae achieved competence but at a slower rate than those maintained at 10°C and 15°C.

At present we do not know if there is an optimal temperature regime for the survival and development of *Eunicella verrucosa* larvae. Without this information it is impossible to predict the likely direct effects of future climate change on *E. verrucosa*'s larval survival rates.

Shifts in water temperature are likely to have an indirect influence on larval survival rates for species with a planktonic larval phase. Two key factors influencing the survival of planktonic larvae are the availability of food and the abundance of predatory species within the plankton.

Long term research has established that changes in plankton community structure may be linked to fluctuations in seawater temperature (Southward *et al*, 1995). Any change in the composition of plankton communities is likely to affect the available food supply of, and / or level of predation on, planktonic larvae.

We do not currently know whether the life cycle of *Eunicella verrucosa* includes a planktonic larval phase. We have no information relating to food preference or predation during the larval phases. Without better understanding of the species' larval ecology it is not possible to predict how future variations in plankton communities are likely to influence larval survival.

2.2.4 Larval distribution

As well as influencing water temperature, future climate change is expected to result in alterations to major current patterns (Walther *et al*, 2002). It is known that variations in current can influence the reproductive success of gorgonians which reproduce by broadcast spawning. In a study of the tropical gorgonian *Plexaura kuna*, Coffroth & Lasker (1998) found that localised fluctuations in current speed and direction may influence the likelihood of eggs from female colonies encountering sperm released from male colonies during synchronised spawning events.

Alterations in major current systems are expected to directly affect the geographic range over which planktonic larvae are dispersed. Shifts in species range are expected to result from variations to existing patterns of larval dispersal (Hiscock *et al*, 2001). However successful colonisation of new areas will rely on other factors beyond shifts in larval distribution. As an example the availability of suitable habitat is likely to limit the establishment of *Eunicella verrucosa* populations in newly accessible areas (Reef Research, 2003)

At present we do not know whether *Eunicella verrucosa* reproduces through broadcast spawning or internal fertilisation. We have no information on the duration (or even existence) of a planktonic larval phase & therefore cannot predict the species current dispersal capacity. Better understanding these aspects of *E. verrucosa*'s life cycle will enable predictions to be made on the species' likely response to climate induced changes to ocean current patterns.

3. Monitoring temperate reef species in relation to climate change

3.1 Existing UK monitoring requirements for temperate reef species in relation to climate change

3.1.1 UK Biodiversity Group's Species Action Plan (SAP)

The Species Action Plan for *Eunicella verrucosa* states that “*..the effects that climate change may have on the current UK distribution of this species are not known. Natural environmental factors affecting pink sea-fan populations globally need to be identified in order to differentiate them from local, anthropogenic impacts*”.

The action plan targets outline a need to “*Ensure that the pink sea-fan maintains its current abundance from the 1998 baseline*” and “*Ensure that the pink sea-fan maintains its current geographical distribution from the 1998 baseline*”.

In relation to species management and protection the SAP proposes action to “*Investigate causes of decline and take the appropriate management response where human activities are implicated.*”

In relation to future research and monitoring the plan highlights the need to

- *Continue to monitor the abundance and condition of sea-fans as a part of established monitoring work*

- *Undertake a programme of spot surveys in three years between 1999 and 2004...to be conducted at locations (including) sites at the present limit of distribution...this can be linked to long-term monitoring of climate change.*
- *Research the factors which affect recruitment and survival of pink sea-fan.*
UK Biodiversity Action Group (1999)

The full Biodiversity Action Group Species Action Plan for *Eunicella verrucosa*, (with sections relating to climate change highlighted) is given in Appendix 1.

3.1.2 UK Marine Special Areas of Conservation (SAC's) Project

In relation to Global Warming, the UK Marine SACs document highlights the need to recognise 'natural' temperature-mediated changes in the distribution of subtidal species as "...being distinct from anthropogenic impacts". The document points to the requirement for "detailed monitoring" to reveal any such distribution changes in subtidal communities and calls for "similar formats of monitoring" to be undertaken in adjacent SACs. (UK marine SAC's project, 2003)

3.2 Achieving SAC and SAP requirements

3.2.1 What needs monitoring

To achieve the SAP and SAC requirements detailed above the following monitoring / data collection is considered essential.

- 1) Widescale survey to obtain baseline data on the current range of *E. verrucosa* within UK waters. Repeat surveys to provide comparative data on future population distributions.
- 2) Monitoring of discrete populations using permanent stations to record long-term population dynamics and obtain basic information relating to pink seafan ecology. Long term monitoring should include a focus on factors affecting recruitment & survival and "natural" levels of spatial and temporal population change.
- 3) Widespread & long-term collection of physical data from reef environments to establish baseline information on abiotic parameters and accurately determine levels of future change.

3.2.2 What is being monitored

3.2.2.1 Baseline data on UK seafan population distribution

During 2001 – 2002 the *Marine Conservation Society* (MCS) conducted a survey of seafan populations from South Wales to the Channel Islands. Data on seafan size and condition was collected from populations across SW Britain. The project was largely conducted by volunteer divers, and supported by funding from CCW and the British Sub Aqua Jubilee Trust. It is not currently known whether it will be possible to conduct a repeat survey in the future to provide comparative data.

Details of the seafan survey are available at www.mcsuk.org/dives/seafan.htm

3.2.2.2 Long term population monitoring

Reef Research has been conducting long term monitoring of seafan populations at the East Tennants Reef, Lyme Bay. Since 1998 data relating to recruitment, mortality and colony growth has been collected at a permanent monitoring station (Munro, 2001; Munro, 2002) An ongoing study of the species' reproductive cycle was set up in 2002, in conjunction with Skomer Marine Nature Reserve (Munro & Munro, 2002). A genetics based study aimed at determining patterns of larval dispersion is to be implemented this year. Details of all monitoring work undertaken by *Reef Research* are available at www.reef-research.org.

Patterns of growth and mortality of *Eunicella verrucosa* populations within Skomer MNR are monitored on an ongoing basis by the Skomer marine team.

Dorset Wildlife Trust is currently setting up a study to research growth and recruitment of seafans at Worbarrow Tout, Purbeck. It is anticipated that the study will run for three years.

To our knowledge no other long term monitoring of *Eunicella verrucosa* populations is currently being undertaken.

3.2.2.3 Physical data collection

3.2.2.3.1 Seabed and sea surface temperature data

It is widely believed that monitoring of UK seabed temperature is conducted on an ongoing basis by the *Environment Agency* (EA). Infact the EA only records seabed temperature on an *ad hoc* & mainly short-term basis, to meet the demands of specific projects (such as monitoring thermal discharges). The EA does not conduct any wide-scale or long-term seabed temperature monitoring. The EA does conduct regular monitoring of sea surface temperature (SST) to determine the quality of bathing waters and shellfish areas. The *Environment Agency's* SST monitoring is conducted over broad spatial and temporal scales (Environment Agency, pers. comm.).

Sea Surface Temperature data has limited relevance to the local temperature regime of sublittoral reef communities. This is because

- Considerable variation will occur between localities within one "region" (region being the spatial unit used for data collection / analysis). As an example a general temperature record for the "Bristol Channel" (covering both North Devon to South Wales coasts) may not match local records for Lundy or Skomer (though both sites would be considered within the Bristol Channel region).
- It is inappropriate to infer seabed water temperatures from temperature data collected from surface waters. The temperature regime of surface waters may fluctuate considerably in comparison with seabed temperatures which are often more stable. Comparison of two years' temperature monitoring data from Skomer MNR is shown in Figures 3a & 3b. The Skomer data indicates that within a single site, water temperatures recorded at depths of 1m and 15m can differ by between 0°C and 1.65°C.

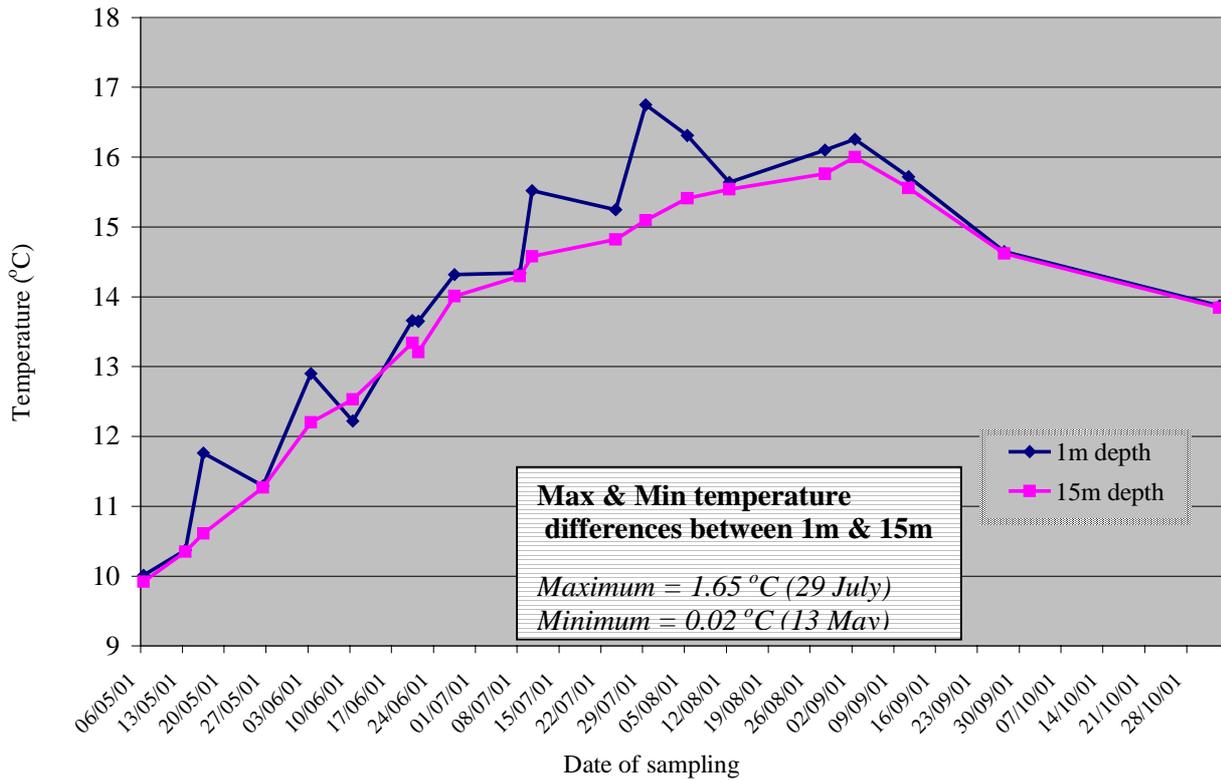


Figure 3a Showing differences in temperature recordings taken at 1m and 15m depth at Skomer MNR between May and October 2001. Dates on which the maximum and minimum difference between water temperature readings at 1m and 15m were observed are tabulated.

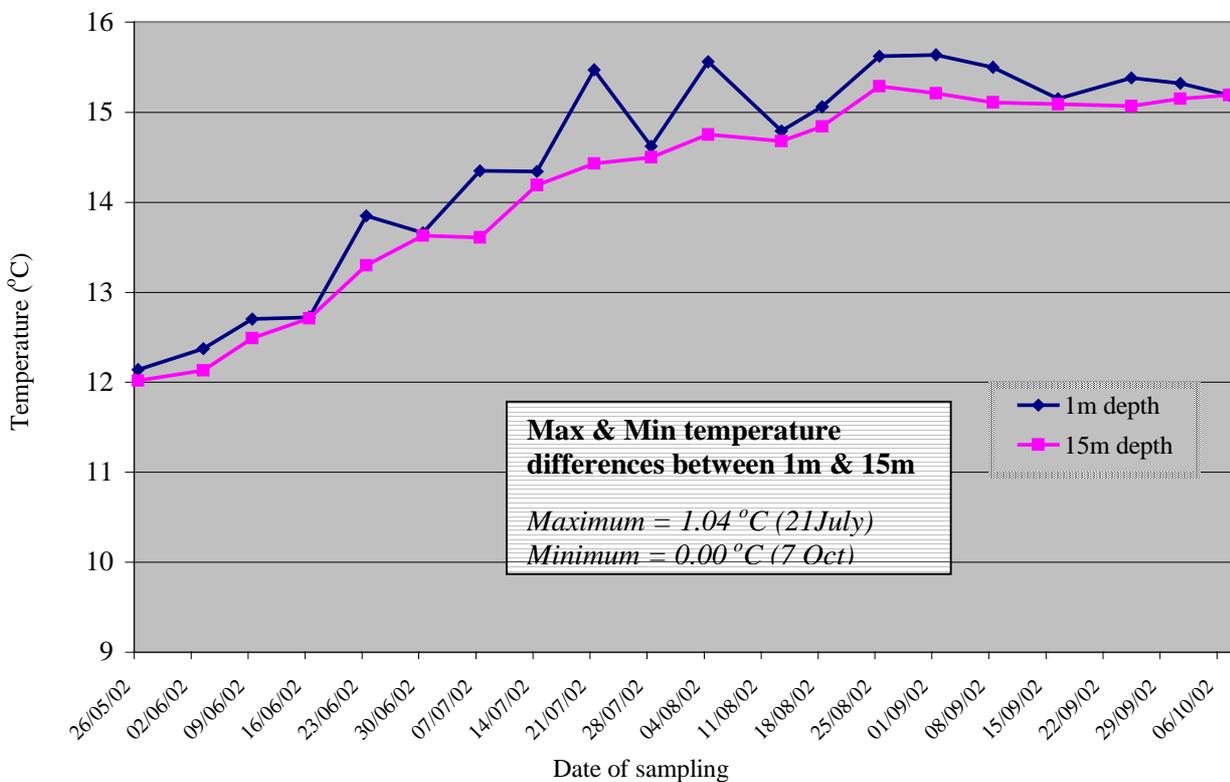


Figure 3b. Showing differences in temperature recordings taken at 1m and 15m depth at Skomer MNR between May and October 2002. Dates on which the maximum and minimum difference between water temperature readings at 1m and 15m were observed are tabulated.

NB. The water temperature difference of 1.65°C (described above) is as great as the overall rise in water temperature change predicted to occur in the next 50 – 100 years.

3.2.2.3.2 Use (& misuse) of SST in predictions of marine temperature change

To our knowledge the majority of predictions of temperature change for UK coastal waters are based on models utilising Sea Surface Temperature (SST) data. This is perhaps because very limited data exists for UK seabed temperatures. However, attempts to correlate the biogeographic distribution of UK temperate reef species with sea surface temperatures and are likely to provide false results (see “Seabed and surface temperature data” section).

Many key publications use loose terms such as “seawater temperature” and “sea temperature” when outlining predictions for climate change relation to the marine environment. It often remains unclear whether they refer to changes in Sea Surface Temperature or seabed temperature. Examples of such publications are given below.

- *Marclim* present potential climate change scenarios from the UK Climate Impacts Programme (UKCIP). They predict “annual temperature averaged across the UK may rise between 2°C... and 3.5°C”. They state that “The **temperature of UK coastal waters** will also increase, although not as rapidly as over land”. All graphical data presented on the *Marclim* website to illustrate future “seawater temperature change” is based on SST data. (Marclim, 2003).
- In reference to expected change in the marine climate, Hiscock *et al*, (2001) predict that by 2100 “..**seawater temperatures** may be as much as 2°C higher than in 2000”. It is not stated whether this change is expected to occur throughout the water column or just for surface waters.
- The UK marine SAC’s project website refers to “..predictions of **temperature rise** as a consequence of global warming...from 0.5°C to 2.5°C by 2030” (UK marine SAC’S project, 2003). It is not clear whether the stated rise in temperature relates to land, air, sea or the seabed.

3.2.2.3.3 Existing seabed temperature data

The collection of regional **seabed** temperature data is considered essential for monitoring the response of sublittoral reef species, populations & communities to climate change.

To our knowledge very few records exist for seabed temperature around the UK. All known UK seabed water temperature data sets are summarised in Table 3.

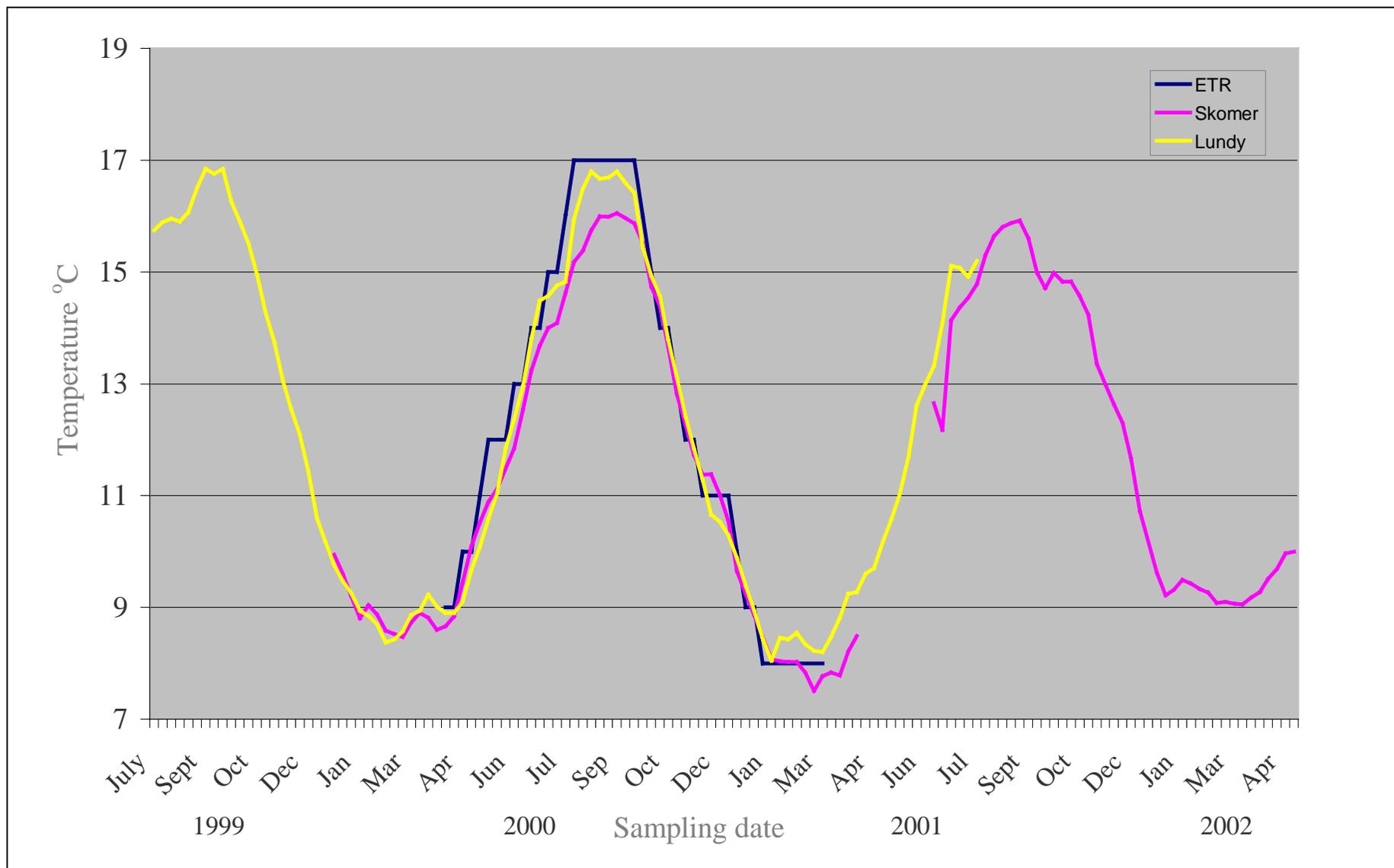
Programmes of continuous seabed water temperature monitoring have been conducted at three sites (Lundy, Skomer and East Tennants Reef). At all three sites temperature dataloggers were used to record seabed water temperature over extended periods. Between the three sites, data sets only overlap for one period (2000-2001). A graphical comparison of the “long-term” data generated from Lundy, Skomer and ETR seabed temperature recording programmes is given in Figure 4. It seems

Table 3. Summarising details UK seabed temperature monitoring programmes by Organisation (showing duration of monitoring, frequency of data points, sites sampled, depth of sampling and subsequent use of data)

Organisation	Duration	Frequency	Site	Depth of data collection	Use of data
English Nature	July '99 – Aug '01	Every 6 hours	Lundy	18m bcd	n/a
Coutryside Council for Wales	Jan '00 – Present	Daily	Skomer	18.5m bcd	Skomer team Used as environmental correlate in annual eel-grass monitoring survey
	July '95 – Dec '95 Mar '96 – Dec '96 Aug '97 – Dec '97 May '98 – Nov '98 May '99 – Sept '99 May '00 – Oct '00 May '01 – Sept '01 May '02 – Oct '02	Weekly		1m, 5, 10m, 15m & nearbed collected at each sampling	Incorporated in factor survey considering all physical attributes related to marine environment of Skomer External research Examples of research using Skomer temperature data include; <i>Re-appearance of rare red algae at northern limits of their British distribution</i> (C. Maggs); <i>Distribution of zostera around Milford Haven</i> (R.Irving); <i>Epifaunal growth on zostera</i> (C.Maggs / F. Bunker); <i>Reproduction in Eunicella verrucosa</i> (Reef Research)
Scottish Natural Heritage	No seabed temperature data collected	n/a	n/a	n/a	n/a
Reef Research	April 00 – Mar '01 Aug'02 – Present	Daily	East Tennants Reef	23m bcd	Reef Research Used to provide information on physical environmental background for observed patterns of growth, mortality, recruitment and reproduction of E.verrucosa. Available to any interested parties via the Reef Research website.
Environment Agency	No provision for the regular monitoring of seabed water temperatures. Short-term data sets collected as and when required (eg point data for EIAs relating to thermal discharges). Consistent repeated monitoring of seawater temperature conducted for surface waters only.				

****Details of access to data shown in this table are listed in Appendix 2**

Figure 4 Comparing seabed water temperature information collected from Lundy, Skomer and East Tennants Reef (ETR) between July 1999 and April 2002. To facilitate data comparison, detailed records have been averaged to give weekly data points for each site. Breaks in data due to removal of data loggers for downloading. Monitoring at Skomer and ETR is currently ongoing – data expected to be available summer 2003.



inappropriate to speculate on the individual temperature regimes of each site from such limited data.

Ongoing continuous monitoring of seabed water temperature is currently conducted at just two sites (Skomer MNR and East Tennants Reef, Lyme Bay).

At Skomer MNR water temperature over a range of depths has been recorded on a weekly basis since 1995. Data is obtained using a probe deployed from a boat. These temperature records are probably the most comprehensive seawater temperature data available for UK waters. The temperature records from Skomer are maintained in a comprehensive format (including data summaries and year on year temperature comparisons) and are readily available on request (Skomer team, pers. comm)

In researching this paper we have found access to existing seabed temperature data far from straightforward. It is likely that additional UK seabed temperature records do exist, but are not readily available.

Accessing available data seems to be complicated by;

- lack of clarity over which agency is responsible for collecting data;
- misconceptions as to what data exists,
- confusion over who holds the data;
- use of out-dated electronic formats for data storage (rendering useful data lost to all practical purposes)

At present there appears to be no central body through which all temperature records can be co-ordinated & made available.

3.2.2.3.4 Limitations of existing seabed temperature data

From Table 3, which summarises existing UK seabed water temperature data sets, it is apparent that;

- **The current monitoring of seabed temperature around the UK is insufficient to determine patterns of spatial or temporal change in thermal regime on any meaningful scale.** (*Permanent monitoring is currently conducted at two sites, Skomer MNR and East Tennants Reef (ETR), Lyme Bay*)
- **The current monitoring of seabed temperature around the UK is insufficient for determining broad changes in species biogeography in relation to climate change.**
- **There is considerable variation between monitoring programmes in terms of the level at which data is collected** (*for example Environment Agency conducts monitoring at discrete sites as and when required. Skomer team has collected weekly data at set depths over past eight years*).
- **There is considerable variation between monitoring programmes in terms of the subsequent use of output** (*Compare for example use of data from Skomer and Lundy*).

4. Use of seabed temperature data in relation to benthic community monitoring programmes

4.1 Links between physical data collection and rationale for biotic monitoring

In the UK a range of marine programmes have been implemented to monitor the biota of benthic communities. Examples include monitoring within Special Areas of Conservation (SAC's), no-take-zones, marine nature reserves and in response to developments which may impact on the marine environment.

One of the primary reasons for monitoring biotic communities is to detect cycles, shifts in equilibrium, or trends which may be linked to other physical or biotic changes. This can give warning of adverse human impacts or facilitate detection of natural cycles or long-term changes (such as those highlighted in individual species and biotope action plans). However, **correlations between physical and biotic events can only be drawn with confidence if the physical conditions likely to influence community structure have also been monitored.**

4.2 Lack of physical data collection to support monitoring of the biota

The collection of seabed temperature data appears to be absent from the most surveys aimed at monitoring the condition of the UK marine environment. In many surveys monitoring of "condition" appears limited to the biotic environment in the (mis)belief that some other agency is collecting physical data which can be used to support biological observations. As shown in Table 3, there is **no** formal collection of temperature data beyond

- a) the Environment Agency's monitoring of SST (which should not be applied to describe the temperature regime of sublittoral communities – see section 3.2.2)
- b) Single point data from Skomer and East Tennants Reef (cannot be extrapolated to describe thermal regime over a wider geographic area).

The current level of marine temperature monitoring is simply inadequate to support biotic data for the majority of benthic marine monitoring projects. It is essential that monitoring of seabed temperatures across the UK be established to determine the response of sublittoral communities to future climate change (and meet SAP, BAP and SAC requirements).

4.3 Examples of biotic response to extreme change in physical environment

In recent years there have been numerous incidents of coral mortality which appear to be linked to changes in the physical environment. Examples of mass mortality events affecting gorgonian communities include:

- Up to 90% mortality of *Briareum asbestinum* colonies in the Florida Keys, USA following high temperature regime associated with El Niño, 1998. (Harvell *et al*, 2001)

- Caribbean-wide epizootic caused by the fungus *Aspergillus sydowii* affecting sea fans *Gorgonia ventalina* and *Gorgonia flabellum*. Epizoite has possibly been facilitated by elevated water temperatures (Kim *et al*, 2000).
- Unprecedented mass mortality of invertebrate communities (including 4 gorgonian species) in the NW Mediterranean following a period of elevated water temperature, summer 1999 (Perez & Garrabou, 2003). This mortality event provides a good example of the potential impacts of environmental stress on temperate reef communities. The event was characterised by mass mortalities in up to 30 benthic invertebrate species, (including the gorgonians *Eunicella singularis*, *Paramuricea clavata*, *Eunicella cavolinii* & *Corallium rubrum*). Mortalities were observed over several hundred kilometres of the Ligurian Sea coast. (Perez & Garrabou, 2003).

Cause and effects of the NW Mediterranean mortality event, 1999

Assessment of the causes and effects of the 1999 mass mortality event has been facilitated where extensive pre and post mortality data has been available

Use of physical environmental data to determine cause

The cause of the 1999 mass mortalities is currently unknown, but it is hypothesised that an anomalous temperature regime played a key role in the event. Long-term monitoring of water temperature, (conducted by Marseilles University) has allowed detailed comparison of the surface and subsurface temperature regimes for the summer of 1999 against previous years' water temperature data.

Water temperature is just one of several parameters monitored in the SOFCOM data series collected by The University of Marseilles. The series is built from a continuous profile of temperature, salinity, dissolved oxygen, pH and chlorophyll concentration taken between the surface and 55m. Recordings have been taken at an offshore station every 15 days since 1994. SOFCOM data is fed into a National record (SOMLIT) through which comparative data is available from monitoring stations at Banyuls, Villefranche, Arcachon, Roscoff, Brest and Wimereux.

The existence of the SOFCOM data has enabled an excellent understanding of the physical environmental context against which the 1999 mass mortality took place. It is known that during the mass mortality event seawater temperature increased by about 6°C at 20m (from 17.3 in 1998 to 23.1 in 1999). Over the same period, the thermocline (usually occurring at 20 to 25m) was pushed down to 40m (University of Marseille, 2003). As a result, it is thought that deeper water invertebrates may have been exposed to temperatures near to or beyond their thermal tolerance. (Perez & Garrabou, 2003).

Biological monitoring to establish effects amongst gorgonian populations.

Observed impacts on gorgonians varied from low level loss of coenchyme tissue to complete mortality. The level and extent of observed damage was highly variable between sites. Some populations of *Paramuricea clavata*, *Eunicella singularis* &

Corallium rubrum seem to have been unaffected by the event, while at other sites mortality rates reached over 80% (Garrabou *et al*, 2001; Perez & Garrabou, 2003).

The existence of baseline ecological information has proved essential for accurate assessment of the impacts and recovery of gorgonian populations from the mortality event. As an example, pre-mortality data on the density and population size structure was available for some affected populations of *Paramuricea clavata*. By comparing pre and post mortality data, Bonhomme *et al* (2003), have been able confirm that “recovery was far from completion three years after the mortality”.

In contrast, assessment of the recovery of affected populations of *Corallium rubrum*, was limited by a lack of basic information relating to the species growth, reproduction, recruitment and post-settlement mortality rates. Similarly, assessments of the severity of tissue necrosis were not possible due to a lack of baseline data on “natural” levels of coenchyme damage in red coral populations (Garrabou *et al*, 2001).

As noted above, the existence of baseline data on biotic and abiotic environments facilitated interpretation of the mortality event observed in the Mediterranean during 1999. In the UK, lack of baseline data (for both biological and physical parameters) limits the potential for sound scientific interpretation of similar mortality events. As an example, Hiscock (2003) has noted recent declines in the marine life around Lundy (England’s only Marine Nature Reserve). The current lack of physical data collection at Lundy leaves us guessing at the physical context within which the observed biological change is occurring.

4.4 Case example of an established sea temperature monitoring programme.

In this section we use an existing sea temperature monitoring programme to illustrate of the type of long-term monitoring which we consider urgently required in the UK.

In 1996 a programme of long-term monitoring of sea temperature was set up on the Great Barrier Reef, Australia. The project aims to provide “fine-scale and accurate temperature data from sites representative of the Great Barrier Reef and adjacent areas for use in reef research and management.” (CRC Reef Research, 2003). Data is collected from over 80 in-situ data loggers deployed at stations across the reef, generally at depths between 5 and 20 metres (see Figure 5). Recordings are made every 30 minutes & data downloaded every 6 – 12 months.

The program was able to record extensive data on the seawater temperature regime during the severe coral bleaching event of 1998. Downloaded data from the loggers is available to all interested parties via the Great Barrier Reef Marine Park Authority website (www.gbrmpa.gov.au/corp_site/info_services/science/seatemp).



Figure 4 Showing location of monitoring stations for the Great Barrier Reef sea temperature monitoring programme. The whole reef area covered by the monitoring programme is shown (right). A localised map (“Townsville inset” from larger map) is shown below. Interactive maps available on the GBRMPA website enable the browser to view & download temperature information from any recording site.

Maps copyright of Great Barrier Reef Marine Park Authority.



5. Recommendations for further research and monitoring

This report has outlined the potential impacts of climate change on temperate reef communities, with particular reference to UK populations of *Eunicella verrucosa*. Our ability to build scientific hypotheses on the likely response of reef species to climate change has been restricted by poor understanding of;

- the ecology of temperate reef species &
- the physical environment of UK sublittoral reefs

A better understanding of the potential impacts of climate change on reef communities could be gained through implementation of the following research and monitoring recommendations.

4.1 Research

Improved understanding of the species' reproductive and dispersal capacity will assist in predicting changes in distribution associated with future warming. We therefore recommend

- Continued research into the environmental cues associated with *Eunicella verrucosa*'s reproductive cycle is needed to determine the influence of temperature on the species' reproductive capacity.
- Research into the genetic composition of adjacent and dispersed to assess the level of interbreeding between and within populations.
- The development of research into the early life history of *Eunicella verrucosa* to allow assessment of larval dispersal capacity and survival rates.

Improved understanding of the relationship between water temperature and spatial distribution will help assess likely range extension / reduction in response to climate change. We recommend

- Research to determine the temperature regime across *E. verrucosa*'s current UK range & in adjacent waters.

Improved understanding of the species' energetics in relation to growth, reproduction & tissue repair / maintenance will help to determine the likely population level effects of tissue damage following temperature stress. We recommend

- Research of *E. Verrucosa*'s physiological response to temperature stress
- Research of potential pathogens & chemical defence systems in *E. verrucosa*.

Generation of long-term data sets on the population ecology of *Eunicella verrucosa* will provide a robust baseline against which future change can be compared. We recommend:

- Continued research to improve data on growth rates, recruitment & mortality levels, reproductive biology, fecundity and age-specific survivorship.

4.2 Monitoring

Continued broadscale monitoring is needed to track changes in species' distribution in relation to climate change. Fine scale monitoring may help detect more subtle responses to climate change (e.g. variations in growth, recruitment and reproduction rates). We recommend

- Repeated broadscale surveys of UK seafan populations to generate comparative data on population distribution from the baseline provided by the MCS' 2001-2002 seafan survey.
- Continued long-term monitoring of discrete populations at Skomer, East Tennants Reef and Purbeck.

Broad scale monitoring of physical parameters is required to establish baseline data & record future changes within sublittoral reef environments. Analysis of biological data in conjunction with physical data is required to determine correlations between physical and biotic events. We recommend

- Implementation of a broad-scale programme for continuous recording of seabed temperature. Location of seabed monitoring stations at points throughout the UK would allow collection of data relevant to many reef communities (not just those supporting seafan populations).

The following questions should be considered to ensure an appropriate monitoring programme is established

- Why is the data needed ?
 - How is it best to collect the data (e.g. depth, frequency of data points, level of precision required) ?
 - How will the data be archived ?
 - How will the data be disseminated ?
 - Who will have responsibility for maintaining data sets ?
 - What electronic sources could be used to improve data accessibility ?
 - Can the data be collected in conjunction with other physical parameters – e.g., current speeds & sedimentation rates ?
- Collection of physical data as part of all ongoing benthic marine monitoring programmes. Analysis of physical data in association with the status of populations / communities.

It is appreciated that the above recommendations are likely to be beyond the scope of any single body, but it is hoped that a range of agencies, academic institutes & NGO's may collaborate to on implementing suggested programmes of research and monitoring.

References

- Acosta, A. (2001). Disease in Zoanthids : dynamics in space and time. *Hydrobiologia*, **460**,113-130.
- Bonhomme, D., Garrabou, J., Perez, T., Sartoretto, S. & Harmelin, J.-G. (2003). Impact and recovery from a mass mortality event of the gorgonian *Paramuricea clavata* populations on the French Mediterranean coasts. *Geophysical Research Abstracts*, **5**, 10676.
- Brazeau, D. A. & Lasker, H. R. (1989). The reproductive cycle and spawning in a Caribbean gorgonian. *Biological Bulletin*, **176**, 1 - 7.
- Coffroth, M. A. & Lasker, H. R. (1998). Larval paternity and male reproductive success of a broadcast-spawning gorgonian, *Plexaura kuna*. *Marine Biology*, **131**, 329 - 337.
- Coma, R., Ribes, M., Zabala, M. & Gili, J.-M. (1995). Reproduction and cycle of gonadal development in the Mediterranean gorgonian *Paramuricea clavata*, *Marine Ecology Progress Series* **117**, 173-183.
- Coma, R., Gili, J.-M. & Zabala, M. (2002). Seasonality of *in situ* respiration rate in three temperate benthic suspension feeders, *Limnology and Oceanography* **47** (1), 324 - 331.
- CRC Reef Research Centre (2003). CRC Reef Research projects on coral bleaching [Online] Available from <http://www.reef.crc.org.au>. Accessed 10/04/03.
- Dicks, L. (2003). Coral bleaching caused by "malaria of the oceans", *New Scientist*, 11 April 2003.[Online] Available from: <http://www.newscientist.com/news/print.jsp?id=ns99993606>. Accessed 18/04/03.
- Dube, D., Kim, K., Alker, A., P. & Harvell, C. D. (2002). Size structure and geographic variation in chemical resistance of sea fan corals *Gorgonia ventalina* to a fungal pathogen. *Marine Ecology Progress Series*, **231**, 139 - 150.
- Garrabou, J., Perez, T., Sartoretto, S. & Harmelin, J.-G. (2001). Mass mortality event in red coral *Corallium rubrum* populations in the Provence region (France, NW Mediterranean). *Marine Ecology Progress Series*, **217**, 263 -272.
- Grigg, R. W. (1977). Population dynamics of two gorgonian corals, *Ecology* **58**, 278 - 290.
- Goreau, T.J. (2003). Climate change impacts have been underestimated, making action more urgent than recognised. Briefing paper for delegates to the framework convention on climate change negotiations. Kyoto, Japan. December 1-16, 1997. Bairiki, Tarawa, Republic of Kiribati; October 28, 1997. Revised, December 1, 1997. [Online] Available from: http://globalcoral.org/climate_change_impacts_have_been.htm. Accessed 03/04/03
- Harmelin, J.-G. & Marinopoulos, J. (1994). Population structure and partial mortality of the gorgonian *Paramuricea clavata* (Risso) in the North-Western Mediterranean (France, Port-Cros Island). *Marine Life*, **4**, 5-13.
- Harvell, C. D., Kim, K., Quirolo, C., Weir, J. & Smith, G. (2001). Coral bleaching and disease: contributors to 1998 mass mortality in *Briareum asbestinum* (Octocorallia, Gorgonacea). *Hydrobiologia*, **460**, 97 - 104.

- Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S. & Samuel, M. D. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science*, **296**, 2158-2162.
- Hiscock, K., Southward, A. J., Tittley, I., Jory, A. & Hawkins, S. (2001). The impact of climate change on subtidal and intertidal benthic species in Scotland. *Scottish Natural Heritage, (Survey and Monitoring Series)*.
- Hiscock, K. (2003). Mystery of Lundy's disappearing marine life. *MBA News*, **29**, 9.
- Kim, K., Harvell, C. D., Kim, P. D., Smith, G. W. & Merkel, S. M. (2000). Fungal disease resistance of Caribbean sea fan corals (*Gorgonia* spp.). *Marine Biology*, **136**, 259 - 267.
- Kuta, K.G. & Richardson, L.L (1996). Abundance and distribution of black band disease on coral reefs in the northern Florida Keys. *Coral Reefs*, **15**, 219 – 223. Cited in; Harvell, C. D., Kim, K., Quirolo, C., Weir, J. & Smith, G. (2001). Coral bleaching and disease: contributors to 1998 mass mortality in *Briareum asbestinum* (Octocorallia, Gorgonacea). *Hydrobiologia*, **460**, 97 - 104.
- Marclim. (2003). Climate change information. [Online] Available from: http://www.mba.ac.uk/marclim/is_our_climate_changing.asp. Accessed 22/03/03
- McCormick, M. I. & Molony, B. W. (1995). Influence of water temperature during the larval stage on size, age and body condition of a tropical reef fish at settlement. *Marine Ecology Progress Series*, **118**, 59 - 68.
- Munro, A.S., 2001. *East Tennants Reef Seafan Project Field Report, April 2001. A report to English Nature. RR Report 4/2001 ETR 02. Reef Research, Crediton, UK [Online]*
Available from; http://www.reef-research.org/pdf_rpts/RR_Rpt_4_2001_ETR_02.pdf
- Munro, A.S., 2002. *East Tennants Reef Seafan Project Interim Report, March 2002. A report to English Nature RR Report 3/2002 ETR 04b. Reef Research, Crediton, UK [Online]*
Available from; http://www.reef-research.org/pdf_rpts/RR_Rpt_3_2002_ETR_04b.pdf
- Munro, C.D. & Munro, A.S. (2002). Determining the reproductive cycle of *Eunicella verrucosa*. A report to the Countryside Council for Wales. RR Report 9/2002 ETR 05. Reef Research, Crediton, UK [Online]
Available from; http://www.reef-research.org/pdf_rpts/Rpt_ETR_05_Sep_2002.pdf
- Munro, L. & Munro, C.D. (2003) *East Tennants Reef Seafan Project Determining the reproductive cycle of Eunicella verrucosa. Interim Report, March 2003. A report to the Countryside Council for Wales. RR Report 3/2003 ETR 07a. Reef Research, Crediton, UK [Online]*
Available from: http://www.reef-research.org/pdf_rpts/RR_Rpt_3_2003_ETR_07a.pdf
- Nagelkerken, I., Buchan, K., Smith, G. W., Bonair, K., Bush, P., Garzon-Ferreira, J., Botero, L., Gayle, P., Harvell, C. D., Heberer, C., et al. (1997). Widespread disease in Caribbean sea fans: II. Patterns of infection and tissue loss. *Marine Ecology Progress Series*, **160**, 255-263.
- Pennington, J. T., Tamburri, M. N. & Barry, J. P. (2003). Development, temperature tolerance and settlement preference of embryos and larvae of the Articulate Brachiopod *Laques californianus*. Monterey Bay Aquarium Research Institute, 7700

Sandholdt Road, Moss Landing, CA 95039, USA. [Online] Available from:
<http://bonita.mbnms.nos.noaa.gov/research/techreports/trbrachiopod.html>
Accessed 15/03/04

Perez, T. & Garrabou, J.(2003). Mass mortality of marine invertebrates in the NW Mediterranean (Summer 1999). Centre d'Océanologie de Marseille, UMR 6540 DIMAR, Station marine d'Endoume, Rue de la batterie des lions, 13007 Marseille, France. [Online] Available from: <http://biomareweb.org/2.3.html> Accessed 03/04/03

Reef Research, (2003) Reef Research website [Online]
Available from www.reef-research.org Accessed 30/04/03

Richmond, M. D. (1997). *A guide to the seashores of Eastern Africa and the Western Indian Ocean Islands*, SIDA/Department for Research Cooperation, (SAREC) 448pp

Rützler, K., Santavy, D.L. & Antonium, A. (1983). The black band diseases of Atlantic reef corals. III. Distribution, ecology, and development. *P.S.Z.N.I. mar Ecol.* **4**, 329 – 358. Cited in: Harvell, C. D., Kim, K., Quirolo, C., Weir, J. & Smith, G. (2001). Coral bleaching and disease: contributors to 1998 mass mortality in *Briareum asbestinum* (Octocorallia, Gorgonacea). *Hydrobiologia*, **460**, 97 - 104.

Southward, A. J., Hawkins, S. J. & Burrows, M. T. (1995). Seventy years' observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. *Journal of Thermal Biology*, **20**, 127 - 155.

UK Biodiversity Action Group, (1999). Tranche 2 Action Plans. Volume V - maritime species and habitats. In Tranche 2 Action Plans, U. B. Group, ed. (Peterborough, English Nature), pp. 244.

UK Marine SAC's Project, (2003). UK marine Special Areas of Conservation website. [Online] Available from: <http://www.ukmarinesac.org.uk> Accessed 12/04/03

University of Marseille, (2003). An example of the utility of regular observations of the marine environment: the thermic anomaly of the summer 1999 in the Mediterranean and its consequences [Online]. Available from: <http://www.com.univ-mrs.fr/SLT/page12.html>
Accessed 28/04/03

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., Fromentin, J.-M., Hoegh-Guldberg, O. & Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, **416**, 389-395.

Weinberg, S. (1979). Autoecology of shallow-water octocorallia from mediterranean rocky substrata, I. The Banyuls area. *Bijdragen tot de dierkunde*, **49**, 1-15.

Weinberg, S. & Weinberg, F. (1979). The life cycle of a gorgonian: *Eunicella singularis* (Esper, 1794). *Bijdragen tot de dierkunde*, **48**, 127-140.

Appendix 1

Pink sea-fan (*Eunicella verrucosa*) Species Action Plan

1. Current Status

- 1.1 The pink sea-fan *Eunicella verrucosa* is widely distributed in south-west Britain between north Pembrokeshire and Portland (Dorset). In the Bristol Channel the eastward extent is to approximately Combe Martin (north Devon). The pink sea-fan also occurs on the west coast of Ireland and southwards into the Mediterranean.
- 1.2 Sea-fans attach to the rocky seabed usually on upward-facing bedrock or stable boulders at depths below the limit of algal domination (as shallow as 3 m in the turbid waters of north Devon, but more generally deeper than about 15 m). The sea-fan, a passive suspension feeder, is attached to the seabed by a broad base extending to a column. The column may be up to 8 mm in diameter and branches profusely from approximately 20 to 40 mm above the base. The thickness of the branches increases with age and annual growth rings are present in the axis. Branching is usually in one plane, which is orientated at right angles to predominant water currents. At some locations in south-west England, sea-fans occur in 'forests' but in most locations, individuals are widely separated. The species appears to recruit infrequently and large specimens may be as much as 40 years old.
- 1.3 The pink sea fan may be found in the following JNCC Marine Nature Conservation Review (MNCR) biotopes: *Alcyonium digitatum* with massive sponges (*Cliona celata* and *Pachymatisma johnstonia*) and *Nemertesia antennina* on moderately tide-swept exposed circalittoral rock (ECR.AlcMaS) (usually in local shelter); *Phakellia ventilabrum* and axinellid sponges on deep exposed circalittoral rock (MCR.PhaAxi); Erect sponges, *Eunicella verrucosa* and *Pentapora foliacea* on slightly tide-swept moderately exposed circalittoral rock (MCR.ErSEun); Cushion sponges (*Polymastia boletiformis*, *Tethya*), branching sponges, *Nemertesia* spp and *Pentapora foliacea* on moderately exposed circalittoral rock (MCR.ErSPbolSH).
- 1.4 The pink sea-fan is a host species for another BAP priority species: the sea anemone *Amphianthus dohrnii*.
- 1.5 The pink sea-fan is protected under Schedule 5 of the Wildlife and Countryside Act 1981 against killing, injuring, taking possession and sale.

2. Current factors causing loss or decline

- 2.1 The collection as souvenirs, including commercial collection, occurred during the late 1960s and may have reduced populations in the long term.
- 2.2 The effects that climate change may have on the current UK distribution of this species are not known. Natural environmental factors affecting pink sea-fan populations globally need to be identified in order to differentiate them from local, anthropogenic impacts.
- 2.3 The long-term effects of intensive potting and netting on local populations are not known and need further investigation. However, entanglement in fishing nets and line is a problem in some areas; it is known to damage soft tissue and may ultimately severely damage or kill colonies. Fin-strike damage by scuba divers on pink sea-fan colonies may also be detrimental.

- 2.4 Sea-fans can die whilst still attached to the seabed after becoming smothered by other organisms (such as by ephemeral seaweeds at shallow depths during early summer).

3. Current Action

- 3.1 The awareness amongst recreational divers of the long life and slow growth of the sea-fan has been promulgated since the mid 1970s and it is important to retain this education.
- 3.2 Part of the study on the impacts of potting was directed at establishing the importance of bottom gear on the survival of the pink sea-fan. This provided valuable information in determining management measures to protect the species.
- 3.3 The zoning schemes for Lundy and Skomer Marine Nature Reserves (MNRs) were both established to, in part, reflect the sensitivity of the pink sea-fan to various factors. This approach should be extended to other marine protected areas.

4. Action plan objectives and targets

The following targets are the current targets following the 2001 targets review.

T1 Ensure that the pink sea-fan maintains its current abundance from the 1998 baseline
Revised

T2 Ensure that the pink sea-fan maintains its current geographical distribution from the 1998 baseline.
Revised

5. Proposed actions with lead agencies

5.1 Policy and legislation

5.1.1 None proposed.

5.2 Site safeguard and management

5.2.1 Ensure that the management of Special Areas of Conservation (SACs) and Marine Nature Reserves (MNRs) takes account of the pink sea-fan. (ACTION: CCW, EN)

5.2.2 Ensure that areas with significant populations of pink sea-fan in non-statutory (voluntary) marine protected areas are identified as being of appropriate sensitivity within management zoning schemes. (ACTION: CCW, EN)

5.2.3 Undertake management measures to ensure human activities do not compromise known populations of the species. (ACTION: EN, SNH)

5.3 Species management and protection

5.3.1 Investigate causes of decline and take the appropriate management response where human activities are implicated. (ACTION: CCW, EN)

5.4 Advisory

5.4.1 Increase awareness among coastal zone management groups, divers and inshore fishermen of the sensitivity of the pink sea-fan in locations where it is known to exist. (ACTION: CCW, EN)

5.5 Future Research and Monitoring

5.5.1 Continue to monitor the abundance and condition of sea-fans as a part of established monitoring work and ensure that they are included in SAC monitoring programmes, where appropriate. (ACTION: CCW, EN)

5.5.2 Undertake a programme of spot surveys in three years between 1999 and 2004. The surveys are to be conducted at locations where pink sea-fan are known to occur, from 'forest' areas to areas where abundance is sparse. Sites at the present limit of distribution should also be included. This can be linked to long-term monitoring of climate change. The data to be recorded should include density, size structure, colour, 'fouling', percentage 'infestation' by predators (the seaslug *Tritonia nilsodhneri*, and the prosobranch *Simnia patula*). Data is also required on the occurrence and density of the sea-fan anemone *Amphianthus dohrnii* (often found attached to the pink sea-fan). (ACTION: CCW, EN, NERC)

5.5.3 *Research the factors which affect recruitment and survival of pink sea-fan.*
Report by end of 2004. (ACTION: NERC)

5.6 Communications and Publicity

5.6.1 Provide information on the pink sea-fan and *Amphianthus dohrnii*. Distribute as appropriate to recreational divers and lobster potters through leaflets, posters, displays and talks. (ACTION: CCW, EN)

5.6.2 Consider including in public aquaria (with *Amphianthus dohrnii*) to increase general awareness of marine biodiversity. (ACTION: CCW, EN)

5.6.3 Synthesise and disseminate data from existing sea-fan monitoring and research programmes as appropriate. (ACTION: CCW, EN)

5.7 Links with other action plans

None given

Lead Partner:

Wildlife Trusts

World Wide Fund for Nature

Contact Point:

English Nature : Roger Covey

Local implementation

The following local action plans implement this UK plan:

A Local Biodiversity Plan for Pembrokeshire

Action for biodiversity in the South-West, a series of habitat and species plans to guide delivery

Cornwall's Biodiversity vol 1, 2 and 3

Devon Biodiversity Action Plan

Dorset Biodiversity Initiative

Teignbridge BAP

Originally published in:

UK Biodiversity Group Tranche 2 Action Plans - Volume V: Maritime species and habitats

HMSO (October 1999) Tranche: 2 Volume: V Page: 85

*Points relating to climate change are shown in blue text

Appendix 2

Access to seabed temperature records quoted in this report

Reef Research Raw data and summary information available in PDF format at the Reef Research Website (www.reef-research.org), or by contacting Reef Research directly at

1, Orchard Cottages,
Coombe Barton,
Shobrooke,
Crediton,
Devon.
EX17 1BS

enquiries@reef-research.org

English Nature Lundy temperature data available from Lundy Warden

warden@lundyisland.co.uk

CCW Skomer temperature data available from Skomer Marine Team

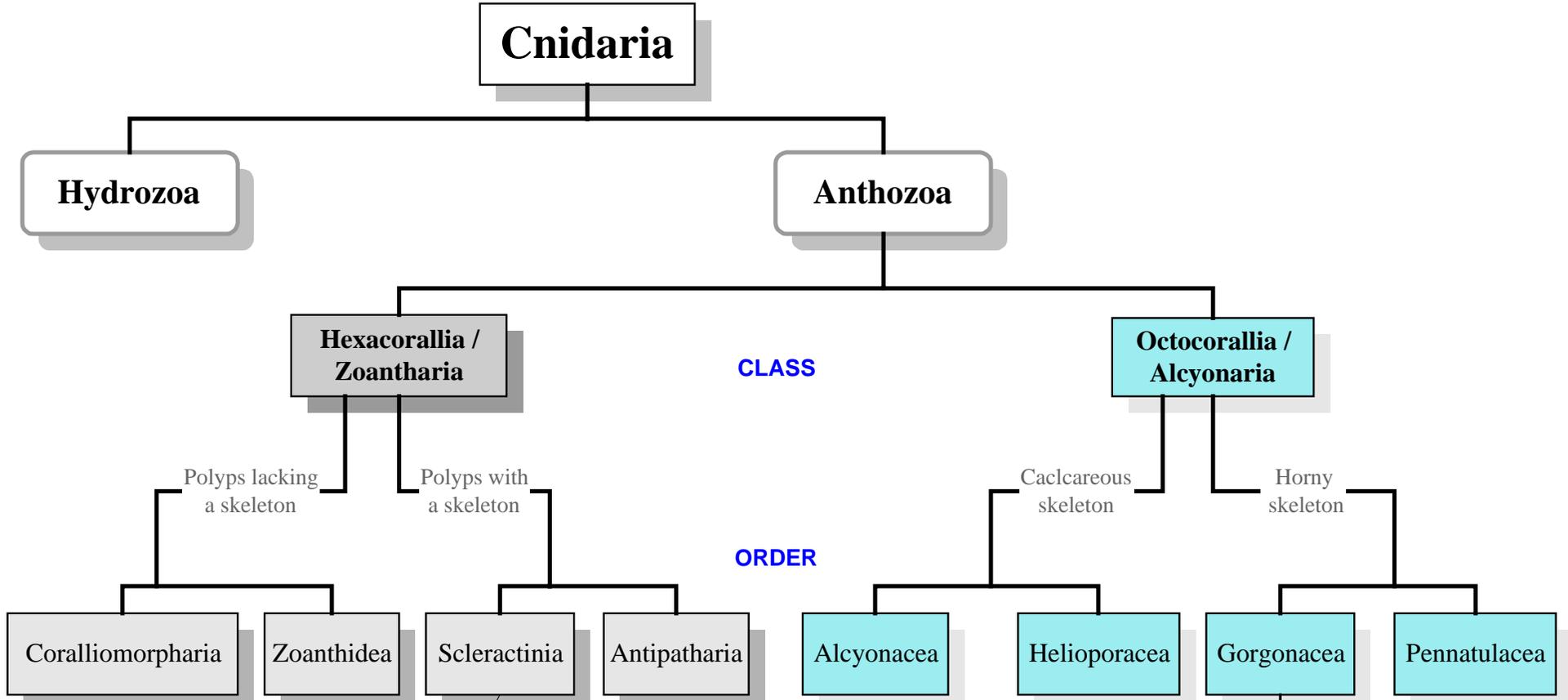
skomer.MNR@ccw.gov.uk

Environment Agency Sea temperature information available from

Tidal Waters Team
Rio House,
Waterside Drive
Aztec West
Almondsbury
Bristol
BS32 4UD

enquiries@environment-agency.gov.uk

<http://www.environment-agency.gov.uk>



CLASS

ORDER

Oculina patagonica

- Eunicella verrucosa*
- Eunicella singularis*
- Eunicella cavolinii*
- Gorgonia ventalina*
- Gorgonia flabellum*
- Lophogorgia ceratophyta*
- Plexaura A.*
- Plexaura kuna*
- Muricea fruticosa*
- Muricea californica*
- Swiftia pallida*
- Paramuricea clavata*
- Briareum asbestinum*
- Corallium rubrum*

Appendix 3

Taxonomic relations between Cnidarian species cited in this report