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Biodiversity conservation in the Galápagos Marine Reserve

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Abstract

The location of the Galápagos Islands at the confluence of warm and cold surface currents and deep, cold, upwelling waters leads to coastal-marine ecological complexity and biological uniqueness which is still only poorly understood (WELLINGTON, 1984; JAMES, 1991). It has a high proportion of endemism in its marine species. There is a close relationship between the marine environment and many of the Galápagos land-based animals. The rich marine and coastal wildlife is vulnerable to the increasing human presence through immigration and tourism (MACFARLAND and CIFUENTES, 1995). Fisheries have led to the depletion of groupers, lobsters, and sea cucumbers (BUSTAMANTE, 1997).

The Charles Darwin Research Station (CDRS) and the Galápagos National Park Service (GNPS) initiated participatory planning (bringing together the principal stakeholders) for the Galápagos Marine Reserve, leading to the incorporation of this approach into the Special Law for the Galápagos, which was approved in March 1998. There is now a strong demand for scientific data on the fisheries and coastal ecosystem to inform decisions in the participatory management group. The CDRS has a programme of complementary scientific and social components which supports the requirements of this group but is constrained by shortage of funds.

Preliminary results from routine CDRS marine surveys and particularly surveys in February 1998 are summarized, which highlight the effects of the 1997-98 El Niño event; bleaching of corals and crustose corallines, mortality of barnacles, and spread of fish species from the north to the south of the archipelago. The absence or very low density of commercially exploited species (lobster, sea cucumber, grouper, sharks) was noted.

A Galápagos Geographical Information System (GIS) is being established to bring together the existing information on species distributions and densities, physical environmental data, and human impacts into a readily accessible and comprehensive form as an essential step for informed management decisions.

Priorities for future research on and monitoring of the Galápagos marine and coastal ecosystem as well the exploited marine resources are suggested.

1. Introduction

1.1. The coastal and marine components of the Galápagos ecosystem

The coastal and marine parts of the Galápagos Islands ecosystem harbour an array of distinctive habitats, processes, and endemic species. The close relationship between terrestrial and marine environments is evident when one considers such prominent Galápagos endemics as the world's only sea-going lizard (the marine iguana), the Galápagos penguin, flightless cormorant, waved albatross, swallow-tailed gull, lava gull, fur seal, and sea lion. The strictly marine flora and fauna of Galápagos are also unique, located as they are at a point where cold currents from the south-east meet warm currents from the north-east, whilst east-moving deep ocean currents up-well along the western side of the platform (WOOSTER & HEDGPETH, 1966; HOUVENAHGEL, 1984; CHAVEZ & BRUSCA, 1991). The ecological complexity of this extraordinary marine life is still only poorly understood but endemism is high (see Table 1) and the islands are noted for their spectacular creatures: sharks, whale sharks, cetaceans, and manta rays amongst them, as well as constant and abundant commercially valuable pelagic fish such as bill fishes and tuna. To date, ca. 3,000 species of marine plants and animals have been described for the Galápagos. This figure has been constantly increasing since 1990 due to new taxonomic and biodiversity inventories that are conducted. Recent explorations of deep-sea communities, especially invertebrates and fishes, are yielding new additions to science and to Galápagos marine biodiversity. Being less isolated, in ecological terms, marine ecosystems tend to have low levels of endemism, so the proportion for Galápagos, is remarkably high. In terms of species richness, the Galápagos marine ecosystem is in the intermediate-to-high range, in comparison with other insular systems (Hawaii, Marquesas, etc.), and its biological communities are less well studied than those archipelagos.

1.2. Pressures on the Galápagos ecosystem

The Galápagos marine and coastal wildlife is vulnerable to inappropriate fishing and to other consequences of human presence and use in the islands. In Galápagos, the population growth rate has been over 5% per year, fuelled by immigration of mainlanders seeking economic opportunities in tourism and fishing (MACFARLAND &

Table 1. – Galápagos known marine biodiversity (up to March 1998)*.

GROUPS	No. of Species	Endemics	% Endemic	Richness**	Level of Study
Mammals	24	2	8%	High	Moderate
Macroalgae (seaweeds)	333	130	39%	High	Poor
Marine birds	19	5	26%	High	Good
Fishes	447	51	11%	High	Poor
Soft bottom communities	390	?	?	High	Poor
Polychaeta (sea worms)	192	50	50%	Intermediate	Poor
Brachyurans (crabs)	20	23	19%	Intermediate	Poor
Caridea & Stenopods (shrimps, prawns)	65	10	15%	High	Poor
Porcelain crabs	12	1	8%	Low	Good
Barnacles	18	4	22%	Low	Good
Mollusks	800	141	18%	Low	Poor
Opistobranchs (nudibranchs)	49	18	37%	Low	Poor
Echinoderms (sea urchins)	200	34	17%	High	Poor
Bryozoans	184	34	18%	High	Poor
Gorgonians (sea fans)	12	8	67%	Low	Poor
Corals	44	20	45%	Low	Moderate
Total	2939	531			

* Sources: JACKSON (1993), MERLEN (1995), HANCOCK (1945), HARRIS (1974), GROVE & LAVENBERG (1997), JAMES (1991), GLYNN & WELLINGTON (1983), HICKMAN (1998), CDRS museum.
** Relative to other Pacific insular areas

CIFUENTES, 1995). The El Niño phenomenon, in full force in 1997-98, compounds the stress on vulnerable coastal and marine species, because it alters dramatically the functioning of ecosystems in the Pacific Ocean. The last big El Niño, in 1982-83, caused populations of many species to crash (ROBINSON and DEL PINO, 1985; ROBINSON, 1987). Some bounced back while others, notably corals and the very rare Galápagos penguin, have never recovered their pre-1982 levels. In contrast, recent findings and more detailed monitoring of El Niño 1997-98 have shown that positive effects are also occurring. Massive recruitment of macroalgae, invertebrates, and some fishes has been recorded as a consequence of the prolonged El Niño, that has led to a longer reproductive season for true tropical species. Consequently, the overall effects and the negative and positive consequences of the El Niño phenomenon on marine biodiversity is being revised in the light of new data (BUSTAMANTE *et al.*, unpublished data).

Tourism is by far the largest economic activity in the Galápagos Islands. Almost all tour activities are concentrated in the coastal-marine areas and their immediate hinterland. The majority of tourism involves cruises of several days, up to two weeks, around the islands' designated visitor sites, with land visits, boat rides, and snorkelling at most of them. Dive tourism is a fast-expanding element of the tourism business, attracted above all by the wealth of big marine animals, especially sharks.

The fishermen of Galápagos practise artisanal fishing with lines and nets, as well as diving for lobster. In addition, industrial fishing boats come from mainland Ecuador and abroad to fish for tuna. In recent years the total fishing pressure, of all kinds, has increased rapidly, with large numbers of medium-sized mainland longliners visiting the islands, as well as many people migrating to Galápagos to make a living from fishing. In addition, the 1990s saw a sudden ''gold rush'' fishery for sea cucumbers to supply the Asian market, a trade which brought in its wake environmental damage, resource depletion, indebtedness of local people, and social havoc. In 1998 that fishery still continues, though illegal and much reduced, and now another lucrative market, for shark fins, is depleting those ecologically important top predators and key attractions of the dive tourism business. It is clear to everyone in Galápagos, including the local fishermen, that returns are diminishing and that effective management of the marine area is needed (BUSTAMANTE, 1997).

1.3. Management of the Galápagos marine reserve

Against this background the Charles Darwin Research Station (CDRS) and the Galápagos National Park Service

(GNPS) initiated in May 1997 a process of conflict resolution and participatory planning for the marine reserve. The process has brought together the Park and the principal stakeholders, i.e. the tourism sector, local fishing cooperatives, conservationists, and the scientists of the CDRS and other collaborative research institutions (e.g. the Universities of Southampton, Heriot-Watt, Houston, and Washington and Lee). Work on a consensus-based management plan is progressing, with an agreed plan expected to be ready by late 1998. But the great achievement to date has been that, by joining forces, the Park and stakeholder groups were able to get their principal points of consensus incorporated into the Special Law for Galápagos almost in their entirety (HEYLINGS, 1998). The law, enacted in March 1998:

— Establishes the Marine Reserve as a legally recognized new category of protected area.
— Creates an Inter-institutional Management Authority, comprising both government departments and stakeholder groups, as the highest decision-making body.
— Charges the GNPS with the management of the Reserve.
— Establishes a Participatory Management Group, or Junta, as a mechanism for stakeholders and the Park to collaborate on joint planning and management for the Reserve.
— Specifies that the fisheries' use of the Reserve shall be exclusively for local artisanal fishermen (to take effect as soon as the new management plan is approved).
— Sets the boundaries of the Reserve at 40 nautical miles from the base line, which is the line joining the outermost points of land of the archipelago. This includes almost all of the ecologically important *bajos* or shallow sea-mounts, nutrient-rich areas, and provides a large area for protection of wide-ranging species, such as marine mammals, seabirds, and sharks.
— Allocates 5% of tourist entry fees for marine reserve management and a further 5% to the Navy to enhance patrolling and enforcement.

This new legal and institutional framework offers an historic opportunity to conserve one of the world's largest (over 140,000 km^2) and most important marine reserves. There is a long way to go before management of the coastal and marine ecosystems can be fully effective, with all partners able to play their respective roles. However, a promising start has been made, and one major consequence is that there is now a channel, and a strong demand, for scientific data on fisheries and the coastal ecosystem, in order to inform the decisions of the participatory management group. The shortage of data on marine biodiversity and resources has been particularly notable during the process, currently underway, of defining the provisional zonation of the marine reserve. There are not sufficient data to define with confidence priority areas for biodiversity, specify key areas for reproduction of target resources such as lobster, or assess the direct and indirect impacts of fishing on marine and coastal ecosystems and their wildlife.

2. The overall marine biodiversity conservation programme of the CDRS

The objective of the overall CDRS marine programme is to guide the development of sustainable, scientifically-based, participatory management of the marine component of the Galápagos ecosystem. The programme has complementary scientific and social components.

2.1. Scientific component: investigation and monitoring

This component comprises the research and advisory work of the CDRS. It has three themes, outlined below, along with the key topics being investigated within each theme:

2.1.1. Research monitoring of the Galápagos marine and coastal ecosystem

— The diversity and distribution of marine and coastal flora and fauna, in order to guide zonation and conservation priorities; the ecology and status of vulnerable endemic species, such as penguins, albatrosses, and marine iguanas, which may need special conservation measures.
— The effects of global change and the El Niño phenomenon on a Galápagos ecosystem already modified by introduced species and human-induced change.
— Monitoring of selected species, biological indicators, oceanographic variables, and productivity; training of research/monitoring staff in CDRS and collaborating organizations.
— Publication of research results.
— Provision of technical guidance on biodiversity issues to the institutions and user groups involved in Galápagos marine management.

2.1.2. Research and monitoring of exploited marine resources

— Assessment of resource stocks.
— Biological studies of commercial species (size, age, growth, mortality, reproduction, recruitment).
— Continue long-term studies of sea cucumber populations, including intensive monitoring of the next proposed harvest.
— Study the direct and indirect effects of exploitation of resources (reef fish, sharks, invertebrates, tuna), including the by-catch problem; trials with local fishermen of methods to prevent/reduce by-catch.
— Training of scientific personnel, managers, and user groups (fishermen, tourism sector).
— Publication of research results; provision of technical guidance on resource management issues to all involved.

2.1.3. Fisheries monitoring

— Improve the accuracy and extend the scope of catch-effort monitoring started in 1997.
— Increase fishermen's participation in fisheries monitoring.
— Maintain and extend the fisheries database; analyze catch data and make results widely available.
— Train all participant groups in use of the fisheries database and interpreting the results of the analysis.
— Facilitate discussion and use of the fisheries data analysis for adaptive management.

2.2. Social component: communication and capacity building

This component covers the process of developing participatory management, strengthening the participating institutions, building awareness and support for marine conservation, and creating a supportive legal and institutional framework. This participatory work is inextricably linked with the scientific work. The process needs not only the results of the scientists' investigations but also the continuous presence of scientists in the discussion and planning sessions, as well as technical training. The principal activities under this component can be grouped in two themes, as follows:

2.2.1. Support to participatory processes for planning and management

— Continue facilitation of consensus-based participatory planning process to complete management plan.
— Continue to give advice and support to the Park as lead management authority; provide technical inputs in appropriate form to the planning group and subsequently the Participatory Management Group (PMG).
— Advise on preparation of regulations under the Special Law; continue to channel local consensus on the Marine Reserve into national decision-making.
— Advise and assist the Park and the Participatory Management Group (PMG) in their dealings with policy-making bodies, including the Inter-Insitutional Management Authority (created by the law), ministries, and INGALA (Instituto Nacional de Galápagos).
— Advise the Inter-Insitutional Management Authority.
— Develop a programme of supporting educational activities for participant groups, the wider Galápagos community, and others concerned in one way or another with the management of Galápagos.
— Produce publications and audio-visual materials for local and national dissemination, in order to generate a climate of support for marine reserve conservation.

2.2.2. Develop the capabilities of the participants in biodiversity conservation

— Help the Park to develop its capabilities to work with Marine Reserve stakeholders.
— Assist the Park to obtain complementary resources to strengthen its marine management capabilities.
— Guide formation of the Participatory Management Group envisaged in the Special Law.
— Build the capacity of the Junta and its component sectoral groups to fulfill their respective roles.
— Involve fishermen and tourism people in monitoring and research activities.
— Provide or facilitate technical training for management plan implementation.
— Assist local groups to implement activities and projects in the framework of the management plan.

3. Recent Research

A benthic marine survey programme was initiated by CDRS in 1995 to examine regularly the biota of some 27 sites around the archipelago. This has compiled taxonomic inventories for fishes, macroalgae, and invertebrates, providing more than 30MB of quantitative data. Eight projects have been specifically evaluating the human impact (fishing, tourism) on biodiversity, whilst other projects are undertaking basic and applied biological research. Most of the funding for the CDRS marine programme has been provided by USAID.

The authors are currently collaborating on a project (funded by the UK Government's Darwin Initiative) to revise the Galápagos marine management plan using scientific data. The timing of this was particularly opportune since there is now a critical need for marine biodiversity data to support demands for protection of specific areas within the Reserve. Overall, there is a hope that the zonation will establish areas permanently free of extractive use, distributed in such a way as to represent the different biogeographic zones within the archipelago. They will complement existing land sites, e.g. important bird colonies will have seaward protection.

3.1. Diving survey

Since the early works of HOUVENAGHEL & HOUVENAGHEL (1974), WELLINGTON (1975, 1984), and GLYNN & WELLINGTON (1983), the benthic communities of the Galápagos marine environment have been little described. Despite the fact that qualitative (invertebrates and macroalgae) and quantitative (fishes) benthic surveys have been conducted since then (GALÁPAGOS MARINE SURVEY, 1994, 1997), the patterns of abundance, distribution, and dynamics of marine biodiversity are still un clear. Diving surveys are logistically difficult and expensive. This current study is continuing the CDRS monitor-

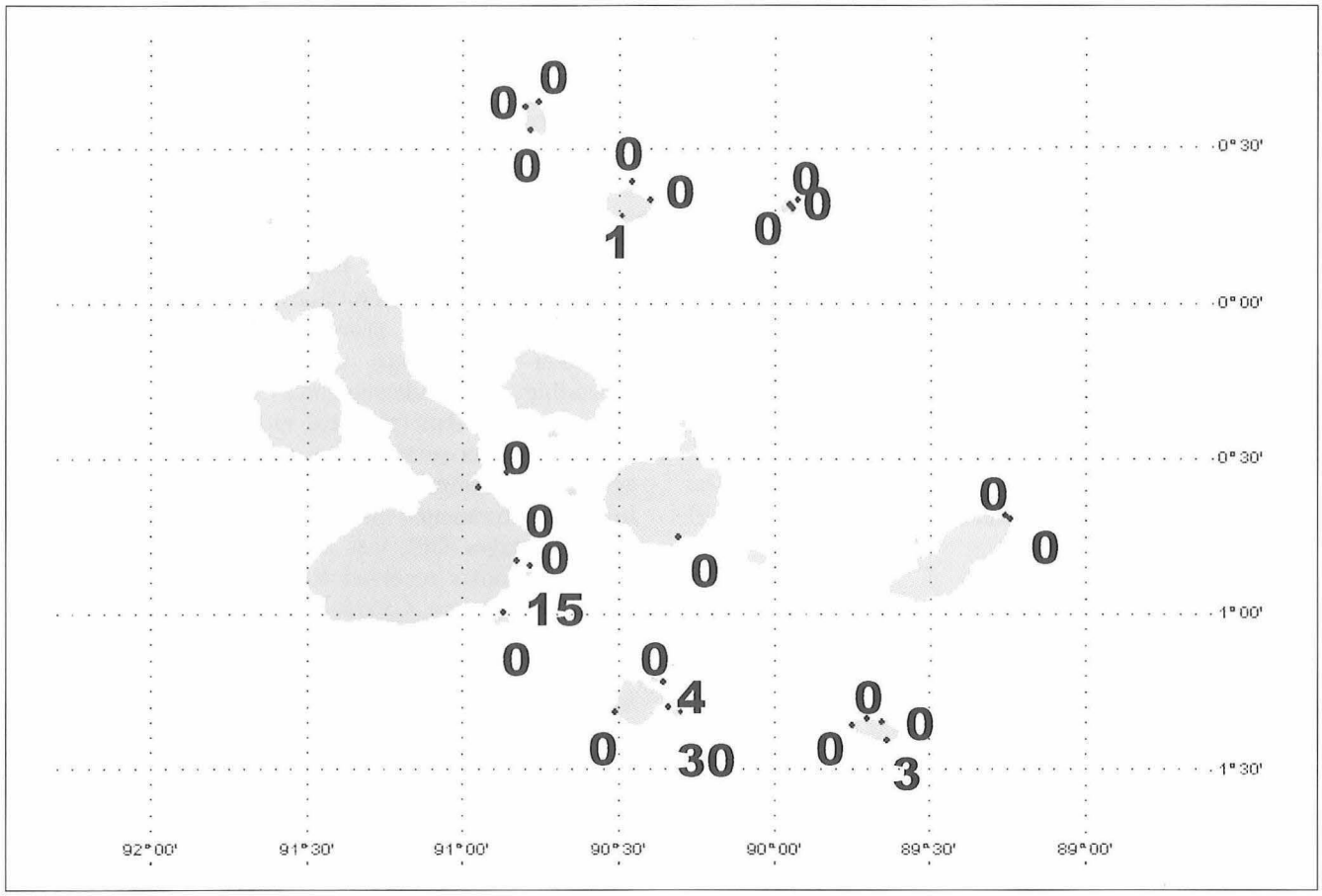

Figure 1. — Location of diving survey sites, February 1998, showing the observed densities, number per $100m^2$, of the commercially exploited sea cucumber, *Stichopus fuscus*.

ing programme as well as undertaking a series of surveys to fill gaps in existing taxonomic and ecological knowledge. Quantitative data is being gathered to identify areas of high conservation value. Additionally this enables a description of the impacts of the current anthropogenic (exploitation) and natural (El Niño) events on the marine communities. Furthermore, each year since 1995, periodic surveys for specimen collection and identification have been conducted as part of collaborative work for producing a series of three field guides for identification of Galápagos invertebrates — ''The Marine Life of Galápagos''. This series includes guides for echinoderms (HICKMAN, 1998), mollusks (HICKMAN & FINET, unpublished manuscript), and crustaceans (HICKMAN & WICKSTEN, unpublished manuscript). The role of CDRS in this project is providing scientific guidance and logistic support, and in return all specimens collected and identified are being deposited in the CDRS museum. As direct results so far, more than 30 new records for Galápagos and several new species for science have been reported.

This section summarizes some of the preliminary results from two cruises aboard the station's vessel *Beagle*, which examined the southern and northern islands in February 1998 (Fig. 1).

Diving survey sites were chosen to be rocky slopes, the most widely distributed habitat type. A 50m transect was laid at each site at depths of between 10 and 15m. A point-intercept-quadrat (1.0 x 0.5m) was used to determine the abundance and coverage of organisms at 5m intervals along the transect. The number of larger, usually mobile, organisms (such as urchins, sea cucumbers, and star fish) were counted within a 1m corridor either side of the 50m transect line. Fish species and abundance were estimated within a 2m wide and 3m high corridor in both directions along the transect line. A complementary fish survey was made using a point-count-census (JENNINGS, 1994) to estimate abundance and species richness comparable to previous work (GALÁPAGOS MARINE SURVEY, 1994, 1997). Any other species (macroalgae, macro-invertebrates, and fishes) in the area were noted. Finally, an estimate was made of the extent of bleaching of coral communities.

3.1.1. Fisheries observations

Commercial fisheries have had a significant effect on certain species (BUSTAMANTE, 1997). The earliest fishery was for the grouper or bacalao (*Mycteroperca olfax*). This has been heavily exploited with a reduction in catch per

unit effort. Survey results show this species to be only occasionally present. In the 1980s the lobster population was over-exploited to the extent that the entire fishery was closed for two years. Only three lobsters were seen during this survey of 25 sites. Following the collapse of the lobster fishery there was an explosion in the sea cucumber or pepino (*Stichopus fuscus*) fishery for the Asian market (CAMHI, 1995). These occur in rocky areas and are collected by diving. Again, very few specimens were observed during the survey with densities of one (or less) per $100m^2$ where formerly there have been typically more than 100 (RICHMOND & MARTÍNEZ, 1993). At the same time as the dramatic rise in exploitation of the sea cucumbers, sharks were also targeted, principally for their fins, again for the Asian market. No sharks were seen during this survey, but this may be partly due to the warmer waters caused by the current El Niño event.

3.1.2. El Niño effects

The Galápagos is experiencing in 1997-1998 elevated water temperatures (4-6 °C) due to a periodic change in water circulation known as El Niño. This happens on a 2-15 year cycle, the last event of this magnitude occurring in 1982-83.

The most well known marine effect is the mortality of corals due to a combination of higher temperatures and high light intensity. This is seen as bleaching. First the symbiotic algae leave the corals and the colony loses colour, becoming white (bleached), then within a few weeks the coral animals die, leaving a bare white coral skeleton. As in the El Niño of 1982-83, the 1997-98 event produced increased mortality of marine iguanas (*Amblyrhynchus cristatus*), sea lions (*Zalophus californianus wollebaeki*, up to 48% in central Galápagos), and sea birds (CDRS, unpublished data).

In the benthic community, there has been a mass mortality of barnacles: at most sites studied only empty shells were observed, coupled with massive bleaching of crustose coralline macroalgae. The recovery of these two groups of species has been fast, however (BUSTAMANTE *et al.*, unpublished data).

Studies of the fish community showed that new colonizations and even hybridization occurred during El Niño events (MCCOSKER, 1987; WELLINGTON, 1975). Also, the reproduction of those fish species which favour warmer waters had been particularly successful during the El Niño period. In particular, new recruits of the wrasse *Thalassoma lucasanum* were very abundant and mean densities were in excess of $5\ m^2$ at some sites. In addition, a number of species such as the trumpetfish *Aulostomus chinensis* and cornetfish *Fistularia commersoni*, which were formerly uncommon in the southern area of the archipelago, are in 1998 relatively abundant and widespread, being recorded at 17 and 20 of the 24 sites surveyed respectively. A number of species which favour cooler water and which were observed in a 1991 study of fishes in the islands were not observed at any site during the course of this survey. It is assumed that these species such as the dusky chub *Girella freminvillei* had retreated to deeper, cooler waters during the El Niño event (S. JENNINGS, pers. com.).

3.2. Galápagos Geographical Information System

Geographical Information Systems (GIS) can be described as a technique that is used for the storage, integration, manipulation, analysis, modelling, and presentation of data. It provides a means of assembling computer based maps and databases in a rapidly accessible and understandable form. Furthermore, a wide variety of data (physical, biological, socio-economic) can be inter-related, thus assisting in making management decisions. Such systems have wide application in environmental management and the establishment of a Galápagos GIS, was a high priority. In 1997 two CDRS scientists received training in GIS (Tydac Research Inc, Ottawa, Canada), beginning work on a Galápagos marine GIS importing maps, bathymetry, and biological data into the system. Existing biological survey data and the results of fisheries surveys will be imported.

The confluence of several ocean currents at the Galápagos produces distinct ecological zones within the archipelago. Satellite remote sensing images can provide a way of visualizing these regions and studying their extent and seasonal and longer term (El Niño) variations. At Southampton two sources of data are being used to produce data for the Galápagos GIS:

— Sea surface temperatures (AVHRR) at 1km resolution, from 1994 onwards;
— Ocean colour measurements (SeaWIFS) at 4km resolution, from summer 1997 onwards, which enable the identification of high chlorophyll (productivity) regions.

The bringing together of information on species distributions and densities, physical environmental data, and human impacts into a readily accessible and comprehensive form is an essential step for informed management decisions. It is essential that the scientific community makes its findings available to the (possibly non-scientific) members of the participatory management group in an understandable form, in order to explain the need for protection of key species and areas.

4. Priorities for future research

4.1. Research and monitoring of the Galápagos marine and coastal ecosystem

4.1.1. Investigate the diversity and distribution of marine and coastal flora and fauna, in order to guide zonation and conservation priorities. The studies will map the distribution of various habitat types (rocky reef, corals, soft bottom, etc.) and the associated flora and fauna, with

particular emphasis on benthic fauna. During these studies, the CDRS museum collection of marine and coastal species will be maintained and expanded. Data on patterns of tourism and fishing use will also be obtained and analysed on a database and GIS.

4.1.2. Undertake research to guide the conservation of endemic coastal and marine species affected by some combination of fishing, tourism, introduced alien species, and El Niño. Targets for study are the albatross, cormorant, penguin, and marine iguana, plus selected invertebrates and macroalgae.

4.1.3. Identify and monitor ecological indicators in distinct management zones of the marine reserve, in order to study trends over time and responses to different management regimes.

4.1.4. Undertake the monitoring of the marine, physical, and chemical environmental parameters around the archipelago.

4.2. Research and monitoring of marine resources and fishing

4.2.1. Fisheries monitoring. Continue the fisheries catch monitoring, database development, data analysis, and training, that was started in early 1997.

4.2.2. Monitor populations of sea cucumbers. Make preliminary observations related to other resource use issues, such as the by-catch problem and the over-exploitation of lobsters. Assist the Park and Junta to decide if and when to have a further season of legal sea cucumber harvesting and to plan and implement all the necessary prior actions, training, licensing, education, etc.

4.2.3. Establish in collaboration with other users a GIS-based marine and coastal ecological monitoring programme.

4.2.4. Research, trials, and training of fishermen, to minimise the by-catch problem. Improve current recording by fishermen of the incidence of by-catch by the artisanal fleet of Galápagos, and verify it with direct field observations. Monitor the effects of by-catch on vulnerable species. Develop mitigation procedures, including improved fishing techniques for reduction of by-catch, drawing on worldwide experience. Provide education and training to assist local fishermen to implement the measures.

4.2.5. Find out about experience elsewhere in shark conservation. Develop a monitoring system for shark populations, including data collection by marine naturalist guides. Estimate shark losses through by-catch and illegal fishing. Advise and assist the introduction of a shark conservation plan, within the framework of the management plan.

5. Conclusions

The Charles Darwin Research Station has adopted a broad approach to the problems associated with Galápagos biodiversity conservation (both marine and terrestrial), which includes research, education, and training. Its commitment to participatory management has proved successful after its first year in breaking out of the state of chronic conflict in Galápagos marine management. If it can be maintained and built upon, then it may hopefully provide the avenue for the adoption of a scientifically based management plan. The scientific knowledge base is essential, especially the long term monitoring programmes. However, these are often less attractive to donors, requiring extended funding for the employment of scientific staff.

The establishment of one of the world's largest marine reserves (second only to the Great Barrier Reef National Park) provides a wonderful opportunity to manage and conserve a unique environment and ecosystem. Provided that an effective marine management plan can be prepared and implemented, there will be every reason to add the GMR to the Galápagos World Heritage Site, which has long suffered from the lack of protection of the marine component of this unique ecosystem.

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