

# Using Biogeography to Help Set Priorities in Marine Conservation

SARA A. LOURIE\* AND AMANDA C. J. VINCENT†

Project Seahorse, Department of Biology, McGill University, 1205 Avenue Dr Penfield, Montréal, Québec, H3A 1B1, Canada

---

**Abstract:** *Biogeographic information has great potential to enhance systematic conservation planning, although it has yet to be routinely incorporated in marine situations. Fundamental differences between marine and terrestrial environments (physical, biological, and sociopolitical) mean that biogeographic data are harder to obtain for marine systems, biogeographic boundaries more difficult to define, and the outcomes of similar conservation approaches may differ. Despite these challenges, an understanding of spatial context, connections, and scales of processes is needed to set conservation priorities that ensure the representation and continued persistence of species and habitats within functioning ecosystems. As we discovered in our review, scientific knowledge of marine systems is increasing rapidly thanks to recent advances in genetics, remote sensing, and geographical information systems. Such knowledge and tools have important implications for marine planning. We also reviewed the degree to which biogeography is incorporated into current marine conservation projects at spatial scales ranging from global to local. Overall, initiatives are becoming more regional in scope and incorporating biogeographic data in an increasingly rigorous manner. However, initiatives that use few or no data are also on the rise and need to be treated with due caution. We recommend undertaking global and regional reviews within biogeographic frameworks; combining analytical approaches to determine biogeographic classifications and to define a range of potential conservation areas with stakeholder involvement to set priorities; understanding contemporary processes that maintain species distributions; and acquiring knowledge of historical distributions to provide appropriate baselines for current conservation. The urgent need for marine conservation, however, means that planning should proceed with the best currently available biogeographic information even while biogeographic research continues.*

**Key Words:** biogeographic classification, ecoregion, marine protected areas, review, systematic planning

Uso de la Biogeografía como Ayuda para Definir Prioridades en Conservación Marina

**Resumen:** *La información biogeográfica tiene gran potencial para mejorar la planeación de la conservación sistemática, aunque aún debe ser incluida rutinariamente a situaciones marinas. Las diferencias (físicas, biológicas y sociopolíticas) fundamentales entre ambientes marinos y terrestres significan que los datos biogeográficos son más difíciles de obtener para sistemas marinos, es más difícil definir los límites biogeográficos y los resultados de métodos de conservación similares pueden diferir. A pesar de estos retos, se requiere entendimiento del contexto espacial, conexiones y escalas de procesos para definir prioridades de conservación que garanticen la representación y persistencia continuada de especies y hábitat dentro de ecosistemas funcionales. En nuestras revisiones descubrimos que nuestro conocimiento de los sistemas marinos está aumentando rápidamente gracias a los avances recientes en genética, percepción remota y sistemas de información geográfica. Estas herramientas han tenido importantes implicaciones en la planeación marina. También revisamos el grado en que la biogeografía es incorporada a los proyectos actuales de conservación en escalas espaciales que varían de globales a locales. En general, las iniciativas se están volviendo más regionales en alcance y están incorporando datos biogeográficos de manera cada vez más rigurosa. Las iniciativas que utilizan pocos o ningún dato también están incrementando y deben ser tratados con la debida precaución.*

---

\*email sara.lourie@mail.mcgill.ca

†Current address: Project Seahorse, Fisheries Centre, The University of British Columbia, 2204 Main Mall, Vancouver, V6T 1Z4, Canada. Paper submitted March 25, 2003; revised manuscript accepted November 13, 2003.

*Recomendamos abordar revisiones globales y regionales en contextos biogeográficos, mediante la combinación de métodos analíticos para determinar clasificaciones biogeográficas y definir un rango de áreas de conservación potenciales y la participación del público para fijar prioridades; el entendimiento de los procesos contemporáneos que mantienen la distribución de especies; y la adquisición de conocimiento de las distribuciones históricas para proporcionar bases apropiadas para la conservación actual. Sin embargo, la urgente necesidad de la conservación marina significa que la planeación debe proceder con la mejor información biogeográfica disponible actualmente aún mientras la investigación biogeográfica continúa.*

**Palabras Clave:** áreas marinas protegidas, clasificación biogeográfica, ecoregión, planeación sistemática, revisión

## Introduction

Biogeography, the study of the geographical distributions of organisms, has the potential to play a pivotal role in systematic marine conservation planning. Systematic planning has been advocated as a method to enhance terrestrial conservation initiatives (Margules & Pressey 2000; Wikramanayake et al. 2002), and similar approaches are needed in marine conservation (Beck 2003). Systematic planning involves an overview of an entire system: identifying conservation targets, collecting information, establishing goals, assessing the contribution of existing areas to reaching goals, assembling a portfolio of areas for consideration, and identifying priority areas for conservation action (Groves et al. 2002). Biogeography can strengthen the scientific basis of conservation planning by providing (1) biological distribution maps at different spatial scales (ecosystems, species, genes); (2) biological distribution models based on environmental surrogates; (3) biologically meaningful classifications within which representative areas can be identified; (4) information on tectonic, oceanographic, physical, chemical, and ecological processes that determine and maintain biological distributions and the spatial and temporal scales at which they operate; (5) tools for analyzing and communicating information.

Marine systems differ from terrestrial systems in ways that have implications for both biogeography and conservation planning (Steele 1985; Carr et al. 2003). Physical connections among areas are typical due to the sea's large size, enormous volume, continuity of habitats, and ubiquitous currents. These lead to biological connections, particularly among organisms that spend part or all of their lives in the pelagic environment (the high density of seawater enables a planktonic lifestyle that is absent among terrestrial biota). The resulting connectivity can be ecological, via individuals or nutrients moving among habitats, or genetic, through movement of propagules. These connections mean that marine systems are truly three dimensional and that biogeographic boundaries may be blurred over space and time.

Societal issues also affect our understanding of marine systems and our management priorities. Only recently have we been able to study aquatic organisms in situ, and

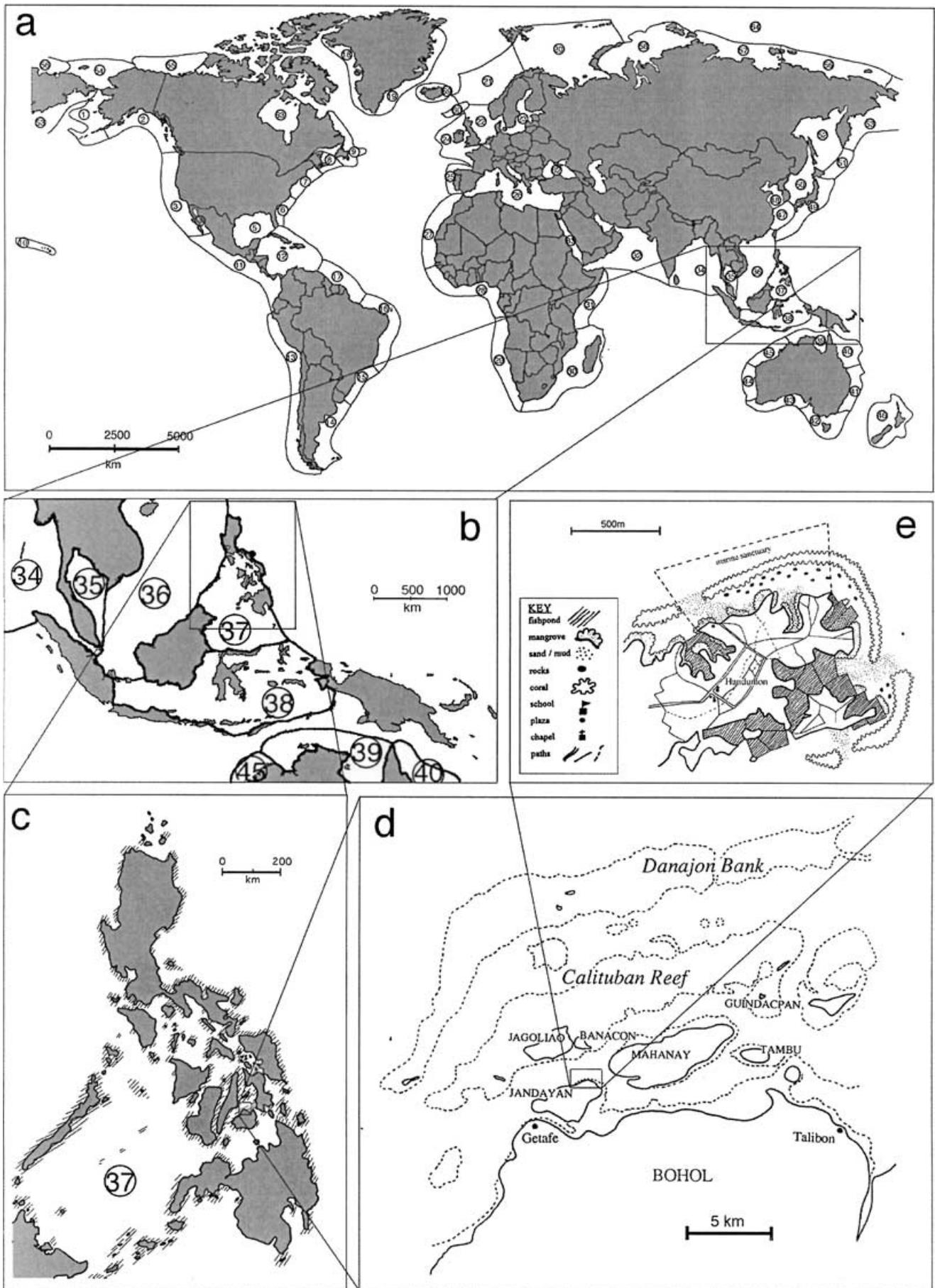
humans are generally unfamiliar with the marine realm, despite our extensive use of the sea and the fact that nearly 40% of the world's population lives within 100 km of the coast (<http://earthtrends.wri.org/>). Our unfamiliarity is reflected in the dearth of scientific data available for systematic planning and in public attitudes toward marine conservation. Furthermore, historical perceptions of fish as resources rather than wildlife, oceans as open-access and infinite, and political division of the oceans into exclusive economic zones (EEZs) that bear no relation to ecological reality all do little to encourage appropriate marine stewardship.

Both marine biogeography and marine conservation lag far behind their terrestrial counterparts (Beck 2003). However, escalating threats to the marine environment (Pew Oceans Commission 2003) and increasing governmental and nongovernmental attention to marine issues (de Fontaubert et al. 1996) argue the need for a solid, appropriate, and objective foundation for decision making. Biogeography could provide such a basis.

We (1) review the current status of marine biogeography, (2) assess ways in which current marine conservation projects incorporate biogeographic information into their planning, and (3) provide recommendations for the future use of biogeography in marine planning.

## The Status of Marine Biogeography

Biogeography can contribute to marine conservation planning in five main areas: (1) biological distributions, (2) models, (3) classifications, (3) processes, and (4) tools, each of which are discussed below. Additional complexity is involved in marine conservation planning because biodiversity exists on a multitude of scales biologically, spatially, and temporally (Fig. 1), and these scales are, to some extent, independent of one another. For example, two species could operate on very different spatial scales even though they are of a similar biological scale (species); one may be very widespread (large spatial scale) and the other may be endemic (small spatial scale). Furthermore, physical processes (climate, seasons, winds, tides, waves), human societies (international conventions, governments, local communities), threats (global warming, chronic



pollution, trampling by tourists), and conservation activities (global, regional, provincial, local) also operate on a variety of spatial and temporal scales.

Conservation initiatives must incorporate a clear understanding of the scale at which they are working and the scales at which their targets (biological units) operate. Conservation priorities may often be set at large spatial scales, yet their implementation will often occur at small scales. Coarse scales of analysis may bring globally significant features into focus but may overlook regionally important ones, even though they may in turn support the globally important ones (e.g., to benefit turtles, both feeding and nesting sites must be protected). Ideally, conservation initiatives at the global, regional, provincial (national), and local level need to be nested and linked through partnerships and collaboration (Costanza et al. 1998; Mace 2000).

### Marine Distributions

Knowledge of marine distributions provides specific information on conservation targets (ecosystems, species, and genes), and forms the basis for biogeographical classifications and future monitoring. As on land, conservation in the sea is moving toward ecosystems (or habitats) as targets (Groves et al. 2002). Additionally, particular threatened, commercial, or habitat-specific species may be an important focus if ecosystem-oriented plans are insufficient (Beck & Odaya 2001).

Global ecosystem (or habitat) mapping has so far been limited to shallow-water coral reefs (Spalding et al. 2001), mangroves (Spalding et al. 1997), and, most recently, seagrasses (Green & Short 2003). These reviews provide appropriate frameworks for global to regional reef, mangrove-, or seagrass-focused conservation priority setting (Bryant et al. 1998). Other biological communities such as kelp forests, oyster beds, deep-water corals, submarine canyons, and seamounts (Richer de Forges et al. 2000; WWF & IUCN 2001) have yet to be comprehensively mapped. Smaller habitat-mapping projects, important for planning at the local level, are also underway in a number of countries (Kendall et al. 2001).

At the next-smaller biological scale, species distributions are primarily known from taxonomic monographs or from field guides. The former are commonly difficult

to access, and the latter often suffer from inaccuracies or oversimplification (Gill 1999). Increasing awareness of the practical importance of taxonomy to conservation, however, is leading to increased funding that should benefit our understanding of species distributions (Vecchione & Collette 1996). Additionally, rapid assessments and species-level inventories are being deployed in geographical areas for which few data exist (Allen & Werner 2002).

At the genetic level, the burgeoning field of phylogeography is providing insights into the spatial context of population and genetic connections (Avice 2000). Phylogeographic studies of marine species are increasing (Muss et al. 2001), although few comparative studies that elucidate general patterns have yet been undertaken.

### Biogeographical Modeling in the Sea

Where detailed species-distribution data are lacking, models based on environmental or habitat data have been used in the terrestrial realm (Kleyer et al. 2000). Such models may be a useful addition to field-based mapping because the latter is often costly and impractical for large areas. However, their use in the marine realm is still relatively new and untested (Mumby & Harborne 1999; Wright & Bartlett 1999; Turner et al. 2003). There is also a role here for reconstructing the historical ranges of species (such as the giant otter [*Pteronura brasiliensis*]), through either palaeoecological studies or modeling, in order to provide appropriate baseline distribution data for conservation planning (Pitcher 2001).

### Marine Biogeographical Classifications

Conservation planning may be systematic from the point of view of individual targets (e.g., selecting the best place to conserve a species of whale) and/or it may be systematic from the point of view of a geographical region (e.g., selecting conservation areas within the Gulf of Mexico). In the latter case, classification schemes are needed to group subareas into biogeographically similar units that can be compared meaningfully. These units can then be used to address goals of comprehensiveness, adequacy, and representation (CAR principles). The CAR principles

---

*Figure 1. Physical, temporal, and biological patterns and processes at various spatial scales and their relationship to various levels of conservation planning: (a) global approximate map scale 1:100 million—ocean basin divisions, major currents, global climate, historical biogeography, highly migratory species, large marine ecosystems (LMEs, marked by numbers); (b) regional, 1:10 million—regional currents, historical biogeography, genetic connectivity, widespread species, individual LMEs or ecoregion; (c) provincial, 1:1 million—small-scale currents, upwelling, genetic connectivity, major habitats within LME or ecoregion (coral reefs marked by diagonal lines), restricted-range species, bioregion; (d) local, 1:500,000—local gyres and eddies, watershed runoff, coastal geomorphology, ecological connectivity, single reef system within one bioregion, planning unit; (e) site, 1:10,000—tides, watershed runoff, ecological connections, habitat specialists, habitats within planning unit, zoning for marine protected area.*

ensure that multiple examples (adequate) of all (comprehensive) types of habitats and ecosystems present within the region (representative) are included within a system of conservation areas (Environment Australia 1999; Day et al. 2003).

Unfortunately, there is still no generally accepted marine biogeographical classification scheme at any spatial scale. The lack of consensus in marine biogeography stems partially from our limited knowledge of the marine realm and partially from the sea's physical nature. Processes affecting abyssal communities differ greatly from those affecting coastal communities, and the three-dimensional and connected nature of marine systems complicate matters further. Distinct boundaries in the sea are generally lacking, particularly in pelagic environments, and broad zones of transition may exist between what are considered biogeographic regions. In some cases these overlap zones, or "biotones," can be larger than the "core provinces" themselves (CSIRO 1996; Environment Australia 1998).

Terrestrial biogeographic regions are generally defined by biomes, or ecological communities of long-lived rooted plants, nested within realms defined by continental plates (Udvardy 1975). Transitions between biomes are relatively swift in space and enduring over a scale of decades. By contrast, phytoplankton dominate primary production in the sea and are hard to map because they are so dynamic in space and time (Longhurst 1998). Although easier to map, "rooted" marine organisms such as kelp, tube-worm colonies, and coral constitute only a tiny fraction of the marine biota and living space.

Marine biogeographical classifications at global and regional scales have been based on climate, ocean basins, oceanography, bathymetry, and biotic distributions (Table 1) (Ekman 1953; Dietrich 1957; Briggs 1974; Bailey 1998; Longhurst 1998). At provincial and local scales, some schemes stress physical characteristics such as coastal morphology, undersea topography, substrate type, wave exposure, and vertical mixing as surrogates for species and habitats (Zacharias et al. 1998; Day & Roff 2000). Others emphasize biotic distributions or some combination of biotic and physical characteristics (Hayden et al. 1984; CSIRO 1996; Environment Australia 1998; Day et al. 2003). At local-site scales, biological features are generally used to modify larger physically defined units (Allee et al. 2000; Davies & Moss 2002).

Consistent and standardized classification systems employed within and among regions would facilitate the assessment of conservation goals. Ideally they should fit into a hierarchical scheme that reflects the variety of scales at which biodiversity operates. It has been argued that "the biogeographic classification scheme used by a country... need not be universally applicable" (Kelleher & Kenchington 1992). However, it is "desirable that regional [and local] classifications be somewhat comparable in order to take into account larger scale bioge-

graphic patterns and processes" (Mumby & Harborne 1999).

In fact, many recent marine classifications have been specifically motivated by the needs of particular governmental or nongovernmental conservation initiatives (Table 1)—for example, large marine ecosystems (LMEs) (Sherman 1993; Duda & Sherman 2002), Interim Marine and Coastal Regionalization for Australia (Environment Australia 1998), Great Barrier Reef Bioregions (Day et al. 2003), the National Oceanographic and Atmospheric Administration (NOAA) marine and estuarine classification (Allee et al. 2000), and the World Conservation Union (IUCN) habitat authority file (DiBenedetto 2002). The Australian regionalization comes the closest to producing a classification scheme that operates on all spatial scales (Environment Australia 1998).

One aspect of marine systems that has yet to be included adequately in biogeographic classifications is their three-dimensional nature. Generally, separation of pelagic and benthic zones is as far as classification schemes go, although a multivariate analysis of the fauna of the Bering Strait shows how biogeographic provinces can be defined in three dimensions (Ray & Hayden 1993). Creative conservation approaches suggest that three-dimensional classification schemes may become more useful in the future (e.g., the Tasmanian Seamounts Marine Reserve has different zoning regulations at different depths [Environment Australia 2002]).

Another issue that is not taken into account in present classification schemes is that the marine realm, even more than the terrestrial, is highly dynamic in space and time. Knowledge of the spatial context of the physical and biological processes that maintain species distributions will help fine-tune marine conservation initiatives, even though these processes are inherently difficult to map at present. Biogeographical connections and movement among areas, rather than static patterns and boundaries, may be a more appropriate way to represent marine biogeography in the longer term (Craw et al. 1999)

### Marine Processes

Although biogeographic patterns are visible, depictable, and valuable to conservation planning, they are merely the outcome of a multitude of dynamic processes. It is these processes that ultimately need to be conserved to ensure the long-term persistence of biodiversity. Scientific knowledge of the relative roles of different processes—such as historical vicariance, oceanography, dispersal, competition, and nutrient flows—in structuring marine communities and determining biogeographic regions is limited. Continuing biogeographic research, however, can help elucidate some of the processes that have been responsible for determining, maintaining, and now altering marine distributions (Briggs 2003). Such knowledge becomes increasingly valuable as climate change

**Table 1. Examples of marine biogeographic divisions at a variety of spatial scales (roughly largest to smallest) and the primary information on which each is based.\***

<i>Divisions</i>	<i>Spatial scale*</i>	<i>Primary basis for classification</i>	<i>Reference</i>
Biogeographic realms	global	major ocean basins (originally based on terrestrial biogeography; Olson & Dinerstein 1998)	World Wildlife Fund 2000
Realms	global	depth and position in water column	Briggs 1974
Biomes	global	oceanic biomes based on prevailing winds plus one coastal biome	Longhurst 1998
Domains	global	climate, water types, ice conditions	Bailey 1998
Hydrographic regions	global	characteristic motions of surface layer (direction, velocity, and persistence of surface currents), ice conditions at higher latitudes	Dietrich 1957
Realms	global	ocean currents, winds, ice, coastal and oceanic	Hayden et al. 1984
Regions	global	climate, depth, fauna	Ekman 1953
Statistical areas	global	political boundaries and arbitrary divisions of oceans	Food and Agriculture Organization 2003
Zoogeographic regions	global/regional	climate, faunal distributions plus one oceanic region	Ray 1975
Ecoregions	global/regional	biomes subdivided by ocean basin and regional oceanography	Longhurst 1998
Divisions	global/regional	domains subdivided by prevailing currents plus continental shelf areas (considered shallow variations of division involved)	Bailey 1998
Subregions	global/regional	faunal distributions	Ekman 1953
Regions	global/regional	climate, currents, faunal changes	Briggs 1974
Large marine ecosystems (LME)	regional	bathymetry, hydrography, trophic dependence	Sherman 1993; Duda & Sherman 2002
Zones	regional	physical characteristics of ocean plus shelf	CSIRO 1996
Biomes	regional	depth and position in water column	CSIRO 1996
Ecoregions	regional	five major habitat types nested within four marine biogeographic realms	World Wildlife Fund 2000
Ecozones	regional	ocean basins, archipelagos, ice regimes, global climate	Zacharias et al. 1998
Provinces	provincial	faunal distributions, especially presence of endemics	Briggs 1974
Provinces	provincial	faunal distributions	Ekman 1953
Coastal biotic provinces	provincial	coastal geomorphology, water mass characteristics, biotic associations	Ray 1975
Provinces	provincial	physical discontinuities (e.g., current divergences), upwellings, sea surface temperatures, faunal distributions	Hayden et al. 1984
Core provinces	provincial	endemic fish distributions	CSIRO 1996
Zootones and biotones	provincial	overlapping fish distributions	CSIRO 1996
Provinces and biotones	provincial	as for CSIRO 1996 plus water mass characteristics and topology	Environment Australia 1998
Meso-scale regions	provincial	biological and physical data, geographic distance along coast	Environment Australia 1998
Ecoprovinces	provincial	ocean surface circulation, continental margins	Zacharias et al. 1998
Ecoregions	provincial	marginal seas, marginal shelf	Zacharias et al. 1998
Major habitat type	provincial	temperature, upwelling, coral reef, continental shelf	World Wildlife Fund 2000
Biogeographical provinces (three dimensional)	provincial	distributions of fish, mammals, and birds	Ray & Hayden 1999
Pacific islands	local	geomorphology	Holthus & Maragos 1995
Domains and subsystems	local	within some enclosed LMEs, basis unclear	Sherman 1993; Duda & Sherman 2002
Bioregions	local	habitats, communities and physical features	Day et al 2003
Ecosystems/communities	local	not yet completed, satellite images and ground truthing	Environment Australia 1998
Ecosections	local	mixing and stratification	Zacharias et al. 1998
Ecounits	local	5 physical factors: current, depth, substrate, topology, exposure	Zacharias et al. 1998
Biounits	local	geomorphology, geology, oceanography, biotic, and ecological features	ANZECC TFMPA 2000
Habitats	local/site	exposure, substrate type, salinity, circulation, biotic characteristics	Ray 1975
National Oceanic and Atmospheric Association habitats	site	primary environmental variables with modifiers to allow general description to become incrementally more specific	Allee et al. 2000
European University Information Systems habitats	site	similar to Allee et al. 2000, but includes freshwater and terrestrial habitats as well as marine habitats	Davies & Moss 2002
World Conservation Union habitats	site	physical and biotic variables	Di Benedetto 2002
Benthic habitat types	site	aerial photographs	Kendall et al. 2001

\*Approximate mapping scales: global, 1:100 million; regional, 1:10 million; provincial, 1:1 million; local, 1:100,000; site, 1:10,000.

alters temperatures, currents, and upwellings (Salm 2002), as anthropogenic actions decimate wild populations, transport species to novel habitats, and pollute from terrestrial sources, and as conservation initiatives strive to maintain connections among populations in an increasingly fragmented and overexploited world (Roberts 1998).

### Methods and Tools

Marine systems present challenges to the collection, collation, analysis, and communication of biogeographic information (Wright & Bartlett 1999). In spite of the difficulties, however, methods and tools are developing rapidly (Palumbi et al. 2003).

The size, depth, and nature of the sea means that humans can only explore it directly with sophisticated technology such as SCUBA and submersibles. Remote sensing—including satellite imaging, aerial photography, and sonar,—is used increasingly to provide data in the form of biodiversity surrogates. Satellite and aerial images are limited, however, because they penetrate only the first few meters of the sea, and ground truthing may be difficult. Still, such data have been used for habitat mapping, classification, and modeling over large geographical areas (Mumby & Harborne 1999; Wright & Bartlett 1999; Turner et al. 2003). Drifters and other in situ measurement devices are providing oceanographic data, while at the other end of the scale ecological and genetic studies are providing information about species-level connections, gene flow, dispersal capabilities, and metapopulation dynamics (Palumbi et al. 2003).

For collating and displaying biogeographic data, spatially explicit geographical information systems (GIS) have become the standard method. Geographical information systems are becoming increasingly useful for marine data, thanks to expanding capabilities for dealing with large, complex, three-dimensional, and dynamic data sets (Wright & Bartlett 1999; Zhang & Grassle 2002).

The Internet has also enabled the construction of centrally compiled and globally disseminated databases that involve hundreds of collaborators around the world (e.g., [www.obis.org](http://www.obis.org), [www.fishbase.org](http://www.fishbase.org) and [www.reefbase.org](http://www.reefbase.org)). Such databases have great potential, especially if they are designed to be flexible and fully updatable. In most cases they now include a simple GIS interface that allows users to create their own maps. As a communication tool these are excellent, but they may give a false impression of data precision, may contain inaccurate records, or may enable users to “zoom in” beyond the scale of resolution at which the data were collected initially. As such databases become more common, it is vital that globally accepted standards are in place, data-set integration is rigorous, data quality is checked, data sources are readily accessible, database architecture is flexible enough to accommodate new data, and users are aware of database limitations (von Meyer et al. 1999).

Biogeographic data analysis is important at two main steps in representative marine conservation planning: first in determining classifications and second, in selecting potential priority areas that will theoretically contribute in an efficient manner toward conservation success. In the past, classifications such as those discussed above have generally been based on qualitative descriptions (Ekman 1953; Briggs 1974; Hayden et al. 1984). More recently, numerical methods (multivariate analysis) have been used to derive classifications by defining clusters of units that share physical (Zacharias et al. 1998) or biological (Ray & Hayden 1993) characteristics or both (Environment Australia 1998). The apparent objectivity and repeatability of such methods are appealing from a scientific point of view, but as with any method the outcome is highly dependent on the underlying data. Different regionalizations may be derived depending on the type of data used, their quality and quantity, the scale at which they are aggregated (i.e., units of analysis), the way inherent variability is treated (e.g., seasonal current changes), and the order in which hierarchical criteria are applied.

An aid in the second step, that of selecting conservation areas, is the growing number of mathematical reserve-selection algorithms for marine applications (e.g., SITES and MARXAN; see [www.ecology.uq.edu.au/marxan.htm](http://www.ecology.uq.edu.au/marxan.htm)) (Possingham et al. 2000). Building on terrestrial approaches to gap analysis, protected-area selection, and adaptive management, these programs seek to achieve specified goals (such as the inclusion of at least 20% of each identified habitat) while minimizing some kind of “cost function” (such as the overall perimeter of the protected areas). Different types of algorithm (e.g., hotspot, greedy, or simulated annealing) operate in slightly different ways (Beger et al. 2003; Leslie et al. 2003). Advantages of quantitative analyses are their scientific basis, objectivity, repeatability, and defensibility. Major disadvantages, however, are that they require extensive data, time, GIS expertise, and understanding of the scientific process.

In situations where data, resources, and time are insufficient to enable numerical analyses, “expert workshops” are sometimes convened (Kramer & Kramer 2002; Ong et al. 2002). These can be used for one or both steps outlined above. In the first (classification) step, biogeographical boundaries are based on consensus opinions from regional experts. In the second (selection) step, regional experts suggest priority areas for conservation action. Such “delphi” approaches have advantages in terms of speed and fewer technical requirements, although they do not produce a scientifically defensible outcome and suffer from a lack of repeatability and transparency. They rarely result in efficient designs (M. Beck, personal communication), and the assumption that they are better than a random guess in areas where appropriate classifications do not exist needs to be tested. They do, however, provide an opportunity for collating existing data sets,

creating initial biogeographic databases, evaluating gaps in biogeographic knowledge, and stimulating future research. A database can form the basis for future review and the next generation of more quantitative marine conservation planning.

Involvement of stakeholders in the second (selection) step, either through “consensus” methods or a more data-driven approach, can lead to broader support for the final conservation decisions than one arrived at by “experts” alone (Mascia 2003).

## Biogeography in Marine Conservation Approaches

Historically, both on land and in the sea, choosing areas to protect has been driven “more by opportunity than design, scenery rather than science” (Hackmann 1995, cited in Day & Roff 2000). Where marine conservation initiatives have been systematic in considering entire systems, efforts have often been target-focused, particularly toward charismatic species such as cetaceans (Reeves & Leatherwood 1994) or ecosystems such as tropical coral reefs (Bryant et al. 1998; Roberts et al. 2002). Meanwhile, other important but perhaps less charismatic or well-known biota such as soft-bottom communities have either been assumed to be conserved *de facto* under the umbrella of the charismatic targets or ignored. Furthermore, marine planning has generally proceeded within the context of political boundaries rather than ecological ones.

An increasing awareness of the interdependence among marine ecosystems has led to the endorsement of ecoregional planning (Beck & Odaya 2001), the CAR principles (Environment Australia 1999; Day et al. 2003;), and a more explicit acknowledgment of ecological and genetic connectivity (Roberts et al. 2003). Furthermore, thanks to long-distance water currents, reproduction and recruitment in the sea may be spatially decoupled so that recruitment in one area is highly dependent upon production elsewhere (Roberts 1998). This leads to the much greater need for “networks” of protected areas in the sea than on land (Sala et al. 2002) and a regional rather than local view of conservation planning (Beck 2003). Informed decisions with respect to these factors depend heavily on biogeographic information.

To assess the degree to which biogeographic information is incorporated into marine conservation planning, we investigated a wide range of marine conservation initiatives that operate at global to local scales. We identified two questions: (1) what types of biogeographic data are consulted (e.g., taxon distributions, biogeographical classifications, and data-regarding processes) and (2) how these data are used to make decisions (e.g., use of biogeographic tools). When possible, we also determined the outputs and current status of each project. This review is

not designed to be exhaustive but to provide an overview of selected conservation programs.

## Biogeographic Data Used

Approaches that use no biogeographic data (e.g., the Gulf of Maine International Ocean Wilderness, initiative 26; the creation of Apo Island Marine Protected Area, initiative 34) create a framework based on political or other nonbiological features (in Table 2).

In site-by-site approaches (i), sites are evaluated individually without a systematic framework. Biogeographical information is limited to a snapshot view of the species present at a particular site, although endemic species may be weighted highly (e.g., Ramsar Convention on Wetlands, initiative 8; World Heritage Convention, initiative 9). Nonsystematic approaches such as these are commonly favored in situations such as international conventions, where implementation is the responsibility of individual countries. In these cases there is no overall plan for each conservation area’s contribution to the goals of the convention.

In the simplest systematic approaches, target taxon ranges may be mapped and assessed in their entirety (ii) (e.g., Conservation International’s hotspots, initiative 5; Reefs at Risk, initiative 4, 14; and South African marine fish hotspots, initiative 28). These provide adequate data for taxon-focused approaches.

To satisfy a conservation goal of representativeness, classifications at appropriate scales are required (iii). These may be based primarily on taxon distributions (iiia) or abiotic factors (iiib). Biogeographic classifications guide programs such as WWF’s Global 200 (initiative 2), Australia’s National Representative System of Marine Protected Areas (initiative 23), and the Great Barrier Reef Representative Areas Program (initiative 25). To the extent that the CAR principles can maintain ecological integrity, these approaches are appropriate. It must be remembered, though, that only mapped habitats can be included in the representation. If the location of sponge beds is unknown, for example, then their representation cannot be assessed.

To achieve long-term persistence of biodiversity, conservation of key ecological processes will be needed (iv). No single approach has yet been developed for objectively including underlying processes into systematic conservation planning. Several initiatives are incorporating processes via oceanography, metapopulation dynamics, recruitment, and whole-watershed planning (e.g., Spratly Islands Marine Park Proposal, initiative 21; the Mesoamerican Caribbean Reef, initiative 16). Dynamic ecosystem modeling, with software such as Ecopath, Ecosim, and Ecospace, could also have implications for conservation planning, although they are currently used for purposes of fisheries management (initiative 10).

Table 2. Selected examples of marine initiatives arranged by descending spatial scale and highlighting the use of biogeography in their planning.<sup>a</sup>

Initiative number and name	Spatial extent	Defined by	Current status	Biogeographic information used (code and selected examples) <sup>b</sup>	Decision-making methods, tools, planning units <sup>c</sup>	Reference
1 Global Representative System of Marine Protected Areas (World Conservation Union [IUCN])	global	existing marine protected areas (MPAs)	initial attempt to review global system of MPAs within a biogeographic framework limited due to lack of agreed-upon biogeographic classification; update due in 2003	i, ii, (iiia, iiib)	opinion based: literature survey, regional working groups, discussions, existing MPAs assessed for their coverage of biogeographic zones and political (country) units	Kelleher et al. 1995
2 Global 200 (World Wildlife Fund [WWF])	global	shelf regions and upwellings	43 priority marine ecoregions defined; guiding principle for WWF's current conservation focus	iiia, iiib	relative scoring and opinion based: representation of habitat types on a global scale; biodiversity value and threat index; planning units are defined ecoregions	WWF 2000
3 High Seas Marine Protected Areas (WWF)	global	seas outside jurisdiction of coastal states	current status unknown; discussion documents in circulation	i, (ii)	ad hoc or opinion based?	Cripps & Christiansen 2001
4 Reefs at Risk (World Resources Institute)	global	coral reefs	used by Conservation International to define hotspots and by WWF to help define priority ecoregions	ii	distribution of biodiversity-related resources outside the jurisdiction of coastal states	Bryant et al. 1998
5 coral reef hotspots (Conservation International [CI])	global	coral reefs	10 hotspots identified in 2002, but current status unknown	ii	distribution of coral reefs mapped onto grid-based database of threats	Roberts et al. 2002
6 IUCN Red List of Threatened Species	global	individual threatened species	basis for species action plans; current status depends on the species	ii	distributions of restricted-range fish, coral, lobsters, and molluscs mapped onto grid-based database of threats	IUCN 2002a
7 Particularly Sensitive Sea Areas (PSSA)(International Maritime Organisation)	global	areas with shipping activity	5 PSSAs established	o, i	species-by-species distributions; habitat modeling	Gjerde 2001
8 Ramsar Convention on Wetlands (United Nations)	global	wetlands (including coastal and shallow marine)	1288 sites already designated (June 2003) including marine and coastal	i, iiia, iv	distribution of ecologically important areas within areas heavily frequented by shipping	RAMSAR 1999
9 World Heritage Convention (United Nations)	global	natural and cultural heritage	730 sites designated (June 2003) including 3-4 marine and coastal; IUCN currently reviewing biogeographic representation of these sites	i	classification of wetland type, watershed processes, migration routes	IUCN 2002b

continued

Table 2. (continued)

Initiative number and name	Spatial extent	Defined by	Current status	Biogeographic information used (code and selected examples) <sup>b</sup>	Decision-making methods, tools, planning units <sup>c</sup>	Reference
10 Sea Around Us Project (Fisheries Centre, University of British Columbia)	regional	large marine ecosystems	used primarily for fisheries management but still largely theoretical	ii, iv time-series distributions of fish biomass based on catch and effort data and stock assessments; habitat modeling	analytical: spatially explicit ecosystem modeling, some data based on expert opinion, planning units are 0.5-degree grid squares	Pauly 2000
11 Latin America and the Caribbean (TNC)	regional	political Exclusive Economic Zone (EEZ) (Central and South America)	brought more funding and attention to Gulf of Panama; in some situations stimulated planners to think on larger scale (e.g., initiative I7), but in general conservation in Caribbean still locally focused	ii, iii, (iv) oceanic circulation, coastal geomorphology, major fauna distributions, classification of coastal systems by primary habitat	relative scoring and opinion-based: expert workshop, indicators as direct/indirect measures of conservation status, ranking among ecoregions within biogeographic provinces and among coastal systems within ecoregions	Sullivan Scaley & Bustamante 1999; K. Sullivan Scaley, personal communication
12 Southern Ocean Whale Sanctuary (International Whaling Commission)	regional	whales	in force since 1993	ii distributions of whales	ad hoc: proposal by France, delimited by ocean basin and by 40°S line of latitude	Reeves & Leatherwood 1994
13 Southeast Asia Regional Marine Programme (IUCN through World Commission on Protected Areas)	regional	political EEZ	current status unknown; working group formed in 2000	(ii, iii, iv) ecoregion classification, mapping of connectivity	unknown, not yet implemented, criteria will apparently include resilience, connectivity, representation	Gomez 2002
14 Reefs at Risk in Southeast Asia (World Resources Institute)	regional	coral reefs in Southeast Asia	widely circulated data set used by local, national, and regional conservation planners to identify priority sites	ii see initiative 6	see initiative 6	Burke et al. 2002
15 Baja to Bering Initiative (Marine Conservation Biology Institute)	regional	political West Coast EEZ of Mexico, U.S.A., and Canada	priority-setting workshop held in early 2003	ii bathymetry, topography, sea surface temperature, chlorophyll data, deep-sea coral records, turtle and whale tracks	opinion-based: expert workshop, base maps, CD-rom of biological and social data available to workshop participants, no standardized planning units	N. Ban, personal communication
16 Mesoamerican Reef (WWF)	regional	WWF ecoregion	guiding principle for WWF's Central America programs and funding priorities in the region; used by many local and national groups as a strategic framework for their conservation actions	ii, (iiib), iv distributions of focal species, oceanography, satellite data, ecological processes (e.g., spawning areas); habitat representation only assessed post hoc, and based on broad categories (i.e., land/watershed, deep water, mangrove, lagoon, lake, coastal)	relative scoring and opinion-based: expert workshop, rankings, drawing on maps, working groups separated first by taxa then by subregion, GIS, 1 × 1 m thematic maps, no standardized planning units	Kramer & Kramer 2002; S. Marin, personal communication
17 Barcelona Protocol (United Nations Environmental Programme [UNEP]-Mediterranean Action Plan)	regional	political EEZ/large marine ecosystem	current status unknown; came into force in 1999; 4 taxon action plans adopted at same time	i site-by-site information on presence of threatened taxa (e.g., monk seal, turtles, cetaceans, marine vegetation)	ad hoc: proposals by individual countries, criteria are historical, cultural, aesthetic, or ecological but no overall framework or planning units, transboundary proposals encouraged	UNEP 2002

continued

Table 2. (continued)

Initiative number and name	Spatial extent	Defined by	Current status	Biogeographic information used (code and selected examples) <sup>b</sup>	Decision-making methods, tools, planning units <sup>c</sup>	Reference
18 Northern Gulf of Mexico Plan (TNC)	regional	ecoregion (inshore bays/estuaries only)	guiding principle for TNC's conservation action in region	ii, iiia, b distributions of focal species and habitats, ecoregion classification	analytical and opinion-based: sites computer algorithm, GIS, expert workshop, planning units are bays/estuaries within subregions of ecoregion	Beck et al. 2000; Beck & Odaya 2001
19 Mid-Atlantic Priority Areas (Natural Resources Defense Council)	regional	fishery management, oil/gas leasing region, federal waters	status unknown; workshop report available on internet	ii, iv distribution of focal species, migratory pathways, nursery areas, physical features (e.g., canyons), oceanography (but no actual data used)	opinion based: expert opinion, drawing lines on maps, no standardized planning units or quantitative data	NRDC 2000
20 Gulf of California (Scripps Institution of Oceanography)	regional	geography	theoretical but apparently incorporated into ecoregional priority-setting plan by WWF and CI	ii, iiia, iv species and habitat distributions, dispersal, oceanography, canonical correspondence analysis to identify zoogeographic regions	analytical: GIS, sites algorithm, planning units are islands, archipelagoes <50 km long, and individual mangroves all within 5 km of shore	Sala et al. 2002; E. Sala, personal communication
21 Spratly Islands Marine Park	regional	larval connectivity	endorsed by IUCN and World Heritage Marine Biodiversity Workshop but not officially included in the South China Sea Marine Planning because of disputes over territorial ownership	iv genetic connectivity, larval dispersal, oceanographic data	opinion based: genetic data	McManus 1994; J. W. McManus, personal communication
22 National Marine Conservation Area System Plan (Parks Canada)	provincial	political EEZ	2 currently operating sites, discussions or work underway for 5 others	iiib large-scale biogeographic regions (see initiative 23); smaller scale not yet integrated	opinion based and ad hoc? research and public consultations, no standardized planning units	N. Ban, personal communication; A. Latourcelle, personal communication
23 National Representative System of Marine Protected Areas (Australia)	provincial	political EEZ	strategic plan endorsed in 1999; current focus on southeast marine region (SEMR); bioregionalization completed; MPAs being created in each of 11 "broad areas of interest"	ii, iiia, b, iv Interim Marine and Coastal Regionalisation for Australia, species distributions, physiographic and oceanographic features, integrated watershed planning	opinion based: stakeholder forums include government, sectoral and scientific experts; "operational criteria" used for identifying and selecting a comprehensive, adequate, and representative (CAR) system of MPAs; "broad areas of interest" as planning units	CSIRO 1996; Environment Australia 1998; M. Carr, personal communication
24 CI priority-setting process (e.g., Philippines)	provincial	CI hotspot (in case of Philippines this is also political)	guiding principle for CI in the Philippines and also national biodiversity action plan	ii, iiia, b, iv reef fish assemblages, geology, connectivity and dispersal features, biogeographic representation, biological importance, habitat quality, research need	opinion based: expert opinion, maps, no standardized planning units	Ong et al. 2002

continued

Table 2. (continued)

Initiative number and name	Spatial extent	Defined by	Current status	Biogeographic information used (code and selected examples) <sup>b</sup>	Decision-making methods, tools, planning units <sup>c</sup>	Reference
25 Representative Areas Program (Great Barrier Reef Marine Park Authority)	provincial	ecology (extent of Great Barrier Reef)	providing guidance for revision of GBRMPA planning and especially siting of new no-take protected areas	biological and physical data sets, geomorphology and oceanography, special features	analytical: biophysical principles provided recommendations for the amount of no-take areas in each bioregion and each known habitat type; MARXAN and TRADER computer algorithms; individual reefs or 10- or 30-km <sup>2</sup> hexagons (in non-reef areas) are planning units	Day et al. 2003
26 Gulf of Maine International Ocean Wilderness (American Oceans Campaign)	provincial	Gulf of Maine continental shelf	proposed in 2000 but not yet in force	none, but being perpendicular to the shore the proposed protected area would contribute greatly to protecting a variety of different marine habitats	ad hoc: based on political boundary	Zeman & Willison 2001
27 United Kingdom Offshore Natura 2000 (European Union Habitats Directive)	regional	political BEZ	not yet in force but will extend the current remit of the United Kingdom's commitment to Natura 2000 (European Union Habitats Directive) to offshore regions	locations of threatened species and habitats	unknown	Johnston 2002
28 South African marine hotspots	provincial	political, inshore	no new MPAs yet in force, but paper has been quoted extensively, and 2 successful funding applications for MPAs have been based on analysis	shorefish distributions, cluster analysis and multidimensional scaling to define biogeographic provinces	analytical: hotspot and complementarity analyses, areas of highest species richness, 50-km-long analysis units along coast	Turpie et al. 2000; L. Beckley, personal communication
29 Great Australian Bight Marine Park	local	geography	current status unknown; in force as of 2000	habitat distribution, distribution of southern right whale and Australian sea lion, Interim Marine and Coastal Regionalisation for Australia	unknown	Environment Australia 2000
30 Extension of Florida Keys National Marine Sanctuary and creation of an ecological reserve	local	MPA boundary	ecological; no-take reserve in force as of 2001	physical oceanography and recruitment, fish and fisheries, benthic communities	opinion-based: expert opinion, GIS, maps of resources and use, drawing lines on maps, discussion, 1-minute grid cells	National Oceanic and Atmospheric Administration 2000
31 Reserve selection in Kimbe Bay, Papua New Guinea	local	geography	theoretical; given to TNC and local nongovernmental organizations and used as first approximation, but MPAs will probably be sited close to shore as result of limited resources	species lists at 37 sites, derive biogeographical classification	analytical: variety of reserve-selection algorithms, sampling sites as planning units	Beger et al. 2003; M. Beger, personal communication

continued

Table 2. (continued)

Initiative number and name	Spatial extent	Defined by	Current status	Biogeographic information used (code and selected examples) <sup>b</sup>	Decision-making methods, tools, planning units <sup>c</sup>	Reference
32 Zoning in Bunaken Marine Protected Area, Indonesia	local	MPA boundary	in force	iiia, iiib habitat distributions (secondary criteria only)	opinion based: stakeholder discussions, primary criteria are tourism related, secondary criteria are habitat distributions	Salm & Clark 2000
33 Ngerumeakoal Channel, Palau (temporal closure)	local	geography	status unknown	iv location of spawning aggregation for grouper and > 50 other species	ad hoc: fish life history and behavior	Johannes et al. 1999
34 Apo Island, Philippines (no-take MPA)	local	geography	protected since 1982	o none	ad hoc: species richness, local community agreement, sociopolitical will	Russ & Alcala 1996

<sup>a</sup>Abbreviations: EEZ, exclusive economic zone; GBRMPA, Great Barrier Reef Marine Park Authority; GIS, geographical information system; IUCN, World Conservation Union; MPA, marine protected area; PSSA, particularly sensitive sea area; WWF, World Wildlife Fund.

<sup>b</sup>Biogeographic information used in each project is assessed as follows: o, no biogeographic information; i, using biological/biogeographic information on a site-by-site basis; ii, mapping individual targets; iii, creating/utilizing biogeographical classifications based on (a) taxon ranges and (b) abiotic surrogates; iv, incorporating processes determining/maintaining biodiversity.

<sup>c</sup>For priority-setting initiatives, the way biogeographic data are used is assessed as ad hoc, opinion-based, relative scoring, or analytical. Tools, methods, and planning units employed are highlighted where known. Question mark indicates approaches that are likely used but unconfirmed as such.

Several initiatives use a combination of approaches, such as taxon focus and biogeographic representation, and thus require a variety of biogeographic data. Examples include ecoregional planning for the northern Gulf of Mexico (initiative 18).

### Priority-Setting Methods

Once the data have been gathered, conservation projects also vary in methods for deciding on priority areas. Ad hoc approaches, such as international conventions that rely on proposals by individual countries (initiatives 7, 8, 9), have no overall framework for comparison. Selection criteria may exist, but the sites are not considered in relation to one another simultaneously. Individual marine protected areas (MPAs) are also often created without a concept of the larger seascape within which they are maintained (e.g., initiatives 33, 34).

Opinion-based approaches, such as Conservation International's priority setting in the Philippines (initiative 24), the Baja to Bering Initiative (initiative 15), and zoning in Bunaken Marine Protected Area (initiative 32) involve delphi or stakeholder workshops. Again, selection criteria may exist, but they are descriptive rather than quantitative and planning units may or may not be formally defined.

In approaches that employ relative scoring, such as WWF's Global 200 (initiative 2), planning units are usually defined. These are assessed against criteria by a transparent scoring method and a simple combination of scores.

Analytical approaches involve mathematical algorithms to define potential sites for conservation action (e.g., The Nature Conservancy's Northern Gulf of Mexico Plan, initiative 18; the Gulf of California, initiative 20; and reserve selection in Kimbe Bay, initiative 31). The simplest of these is exemplified by Conservation International's (CI) hotspots analysis (initiative 5), which identifies areas of highest species richness, endemism, and threat. The appeal of this method is its simplicity, but such comparisons only make sense if they are made between biogeographically similar areas, which is not the case in the CI analysis because it made comparisons across regions (e.g., Caribbean versus Indo-Pacific) (Baird et al. 2002).

Conservation planning that involves analytical methods to determine biogeographical classifications and to define a range of potential sites that fulfill specified criteria, followed by stakeholder involvement to set priorities in a consensus workshop, may be the most expedient approach (Beck 2003).

### Discussion and Recommendations

Our review suggests that marine conservation practitioners are showing an increasing awareness of the need to consider biogeography in their plans. Many older conservation initiatives proceeded primarily on a site-by-site

basis, via ad hoc methods and with limited biogeographical data. More recently, initiatives have become more regional in scope, are beginning to use analytic methods, and include more biogeographic data. These produce more defensible, appropriate, and scientifically credible priorities that enable strategic planning and on-going assessment of achievements with respect to overall goals. Nevertheless, the concurrent rise of initiatives that seem to use few or no data (e.g., NRDC 2000) must be met with due caution.

At the World Summit on Sustainable Development (September 2002), 192 participating nations committed to creating a global representative network of marine protected areas by 2012 and to adopting an ecosystem approach to conservation by the year 2010 (UN/DESA 2002). These goals will be implemented through the Convention on Biological Diversity and its Jakarta Mandate (de Fontaubert et al. 1996) under the guidance of an ad hoc technical expert group which proposes that the “goal for the future should be the development of an effectively managed, ecologically representative global system of marine and coastal protected area networks” (CBD 2002).

To ensure that such systems are truly representative, we need to map marine habitats that are still poorly known. These include oyster beds, rocky reefs, soft-bottom habitats, sponge gardens, deep-sea corals, seamounts, cold seeps, hydrothermal vents, and trenches. We need global and regional reviews, including a formal gap analysis, of existing MPAs and other conservation initiatives that assess projects within a biogeographic framework and assess the representation of habitats, communities, and ecosystems included within marine protected areas in each region. Such a review is already underway for World Heritage sites (World Conservation Union 2002*b*). Ideally, the results of such reviews will help provide a framework for the next generation of marine conservation initiatives.

Other challenges are to understand contemporary processes that maintain species’ distributions, design innovative methods to display them, and find ways to incorporate them in spatial conservation planning. Large Marine Ecosystems and MPA networks are steps in this direction.

On a longer time scale, we need an increased understanding of historical distributions to provide more appropriate baselines and goals for long-term conservation than provided by the distributions of our present impoverished biota (Pauly 1995). To build resilience into our networks, we also need to understand the ephemeral nature of some systems such as hydrothermal vents (WWF/IUCN 2001) and the effect that climate change may have on the distribution of marine diversity (Salm & Clark 2000; Hannah et al. 2002).

We have stressed that biogeography should be at the forefront of determining spatial priorities for proactive marine conservation planning. The spatial distribution and scale of biodiversity, the processes maintaining it, and the threats to it need to be understood so that appro-

priate conservation measures may be initiated. We have highlighted advances in marine biogeography that are enabling us to develop data-rich plans that include information on the distributions of species and ecosystems and some of the processes that determine and maintain these patterns. Some of these advances have been stimulated by the needs of conservation planners, and it is likely that this feedback will continue.

Setting priorities is always controversial, but unless we do so, we risk compromising the long-term persistence of systems. Notwithstanding time constraints imposed by the rapid destruction of marine ecosystems worldwide, priority setting should be based on credible information and scientifically defensible methods while supporting and integrating knowledge as it becomes available. Of course, the final choices of conservation planners will be affected by, and their success ultimately dependent on, many social, cultural, and political factors in addition to biogeographical ones. Nevertheless, biogeography can play a pivotal role in providing the scientific basis for marine conservation planning. We believe that explicit incorporation of biogeography in conservation planning will move us closer to our goals of representative and viable networks of healthy marine systems.

### Acknowledgments

This is a contribution from Project Seahorse. We thank the following people for helpful comments during the evolution of our paper: T. Bernhardt, J. Briggs, D. Browne, D. Green, M. Laxer, G. Llewellyn, K. Martin-Smith, D. O’Brien, J. Rasmussen, M. Samoily, E. Söderström, S. Smith, A. Tewfik, M. Vierros, and T. Werner. We received very helpful reviews from M. Beck, Z. Ferdaña, and H. Leslie. We are also grateful for financial support from a Leverhulme Foundation Study Abroad Studentship, McGill University Trust, and Canadian Commonwealth and McGill Major Scholarships to S.L. and from a McGill University William Dawson Scholarship to A.V. Project Seahorse works in partnership with the John G. Shedd Aquarium (USA) and the Zoological Society of London (UK).

### Literature Cited

ANZECC TFMPA (Australian and New Zealand Environment and Conservation Council Task Force on Marine Protected Areas). 2000. NRSMPA (National Representative System of Marine Protected Areas) strategic plan of action: review of methods for ecosystem mapping for the NRSMPA. Report on action 8. Prepared by Connell Wagner for Environment Australia, Department of the Environment and Heritage, Canberra.

Allee, R. J., et al. 2000. Marine and estuarine habitat classification. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C.

- Allen, G. R., and T. B. Werner. 2002. Coral reef fish assessment in the 'coral triangle' of southeastern Asia. *Environmental Biology of Fishes* **65**:209-214.
- Avise, J. C. 2000. *Phylogeography: the history and formation of species*. Harvard University Press, Cambridge, Massachusetts.
- Bailey, R. G. 1998. *Ecoregions: the ecosystem geography of the oceans and continents*. Springer, New York.
- Baird, A. H., D. R. Bellwood, J. H. Connell, H. V. Cornell, T. P. Hughes, R. H. Karlson, and B. R. Rosen. 2002. Coral reef biodiversity and conservation. *Science* **296**:1026-1028.
- Beck, M. W. 2003. The sea around: planning in marine regions. Pages 319-344 in C. R. Groves, editor. *Drafting a conservation blueprint: a practitioner's guide to planning for biodiversity*. Island Press, Washington D.C.
- Beck, M. W., and M. Odaya. 2001. Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico. *Aquatic Conservation: Marine and Freshwater Ecosystems* **11**:235-242.
- Beck, M. W., M. Odaya, J. J. Bachant, J. Bergan, B. Keller, R. Martin, R. Mathews, C. Porter, and G. Ramseur. 2000. Identification of priority sites for conservation in the northern Gulf of Mexico. The Nature Conservancy, Arlington, Virginia.
- Beger, M., G. P. Jones, and P. L. Munday. 2003. Conservation of coral reef biodiversity: a comparison of reserve selection procedures for corals and fishes. *Biological Conservation* **111**:53-62.
- Briggs, J. C. 1974. *Marine zoogeography*. McGraw-Hill, New York.
- Briggs, J. C. 2003. Marine centres of origin as evolutionary engines. *Journal of Biogeography* **30**:1-18.
- Bryant, D., L. Burke, J. McManus, and M. Spalding 1998. *Reefs at risk: a map-based indicator of threats to the world's coral reefs*. World Resources Institute, Washington, D.C.
- Burke, L., E. Selig, and M. Spalding. 2002. *Reefs at risk in Southeast Asia*. World Resources Institute, Washington, D.C.
- Carr, M. H., J. E. Neigel, J. A. Estes, S. Andelman, R. R. Warner, and J. L. Largier. 2003. Comparing marine and terrestrial ecosystems: implications for the design of coastal marine reserves. *Ecological Applications* **13**(supplement):90-107.
- CISRO (Commonwealth Industrial, Scientific, and Research Organisation). 1996. *Interim marine bioregionalisation for Australia: towards a national system of marine protected areas*. Department of the Environment and Heritage, Canberra.
- Convention on Biological Diversity (CBD). 2002. *Report of the Ad Hoc Technical Expert Group on Marine and Coastal Protected Areas. Marine and coastal biodiversity. UNEP/CBD/SBSTTA/8/9/Add.1*. CBD, Montreal.
- Costanza, R., et al. 1998. Principles for sustainable governance of the oceans. *Science* **281**:198-199.
- Craw, R. C., J. R. Grehan, and M. J. Heads 1999. *Panbiogeography: tracking the history of life*. Oxford University Press, Oxford, United Kingdom.
- Cripps, S. J., and S. Christiansen. 2001. *A strategic approach to protecting areas on the high seas. Marine protected areas on the High Seas: scientific requirements and legal aspects*. World Wildlife Fund, Vilm, Germany.
- Davies, C. E., and D. Moss. 2002. *EUNIS habitat classification. Project C00389*. Centre for Ecology and Hydrology, Huntingdon, United Kingdom.
- Day, J. C., and J. C. Roff. 2000. *Planning for representative marine protected areas: a framework for Canada's oceans*. World Wildlife Fund Canada, Toronto.
- Day, J., L. Fernandes, B. Barnett, S. Slegers, B. Kerrigan, D. Breen, G. De'ath, A. Lewis, J. Innes, and J. Oliver. 2003. *The representative areas program: protecting the biodiversity of the Great Barrier Reef World Heritage Area*. Pages 687-696 in *Proceedings of the ninth international coral reef symposium*. Indonesian Institute of Sciences, Jakarta.
- de Fontaubert, A. C., D. R. Downes, and T. S. Agardy. 1996. *Biodiversity in the seas: implementing the Convention on Biological Diversity in marine and coastal habitats*. IUCN Environmental Policy and Law Paper 32. World Conservation Union, Washington, D.C.
- DiBenedetto, T. 2002. *Proposed modifications to the IUCN habitat authority files, list of habitat qualifiers, and feature-based distribution list as used in the IUCN Species Information Service and the IUCN Red List*. Working document. World Conservation Union Species Survival Commission, Washington, D.C.
- Dietrich, G. 1957. *General oceanography*. Wiley, London.
- Duda, A. M., and K. Sherman. 2002. *A new imperative for improving management of large marine ecosystems*. *Ocean and Coastal Management* **42**:797-833.
- Ekman, S. 1953. *Zoogeography of the sea*. Sidgwick and Jackson, London.
- Environment Australia. 1998. *Interim marine and coastal regionalisation for Australia*. Department of Environment and Heritage, Canberra.
- Environment Australia. 1999. *Understanding and applying the principles of comprehensiveness, adequacy and representativeness for the NRSMPA. Version 3.1*. Report prepared by the Action Team for the ANZECC Task Force on Marine Protected Areas. Environment Australia, Canberra.
- Environment Australia. 2000. *Great Australian Bight Marine Park (Commonwealth Waters) plan of management*. Department of the Environment and Heritage, Canberra.
- Environment Australia. 2002. *Tasmanian Seamounts marine reserve management plan*. Department of the Environment and Heritage, Canberra.
- Food and Agriculture Organization (FAO). 2003. *Major fishing areas for statistical purposes*. FAO, Rome.
- Gill, A. C. 1999. Subspecies, geographic forms and widespread Indo-Pacific coral reef fish species: a call for a change in taxonomic practice. Pages 79-87 in B. Seret and J. Y. Sire, editors. *Fifth Indo-Pacific fish conference. Société Française d'Ichthyologie and Institut de Recherche pour le Développement*, Paris.
- Gjerde, K. M. 2001. *Protecting particularly sensitive sea areas from shipping: a review of IMO's new PSSA guidelines*. Pages 123-132 in H. Thiel, and J. A. Koslow, editors. *Expert workshop on managing risks to biodiversity and the environment on the high-seas, including tools such as Marine Protected Areas: scientific requirements and legal aspects*, World Wildlife Fund, Vilm, Germany.
- Gomez, M. 2002. *Development of a regional action plan to strengthen a network of effective marine reserves in Southeast Asia*. South East Asia WCPA marine workshop: development of a regional action plan to strengthen a network of effective marine protected areas in South East Asia, Bangkok, Thailand. World Conservation Union, Gland, Switzerland. Available from <http://iucn.org/themes/wcpa/biome/marine/seasia/seasia.html> (accessed May 2002).
- Green, E. P., and F. T. Short, editors. 2003. *World atlas of seagrasses*. University of California Press, Berkeley.
- Groves, C. R., D. B. Jensen, L. L. Valutis, K. H. Redford, M. L. Shaffer, J. M. Scott, J. V. Baumgartner, J. V. Higgins, M. W. Beck, and M. G. Anderson. 2002. *Planning for biodiversity conservation: putting conservation science into practice*. *BioScience* **52**:499-512.
- Hannah, L., G. F. Midgley, and R. Millar. 2002. *Climate change with integrated conservation strategies*. *Global Ecology and Biogeography* **11**:485-495.
- Hayden, B. P., G. C. Ray, and R. Dolan. 1984. *Classification of coastal and marine environments*. *Environmental Conservation* **11**:199-207.
- Holthus, P. F., and J. E. Maragos. 1995. *Marine ecosystem classification for the tropical island Pacific*. Pages 239-278 in J. E. Maragos, M. N. Peterson, L. G. Eldredge, J. E. Bardach, and H. F. Takeuchi, editors. *Marine and coastal biodiversity in the tropical island Pacific region*. Program on Environment, East-West Center, Honolulu.
- Johannes, R. E., L. Squire, T. Graham, Y. Sadovy, and H. Renguul 1999. *Spawning aggregations of groupers (Serranidae) in Palau*. The Nature Conservancy, Washington, D.C.
- Johnston, C. M., C. G. Turnbull, and M. L. Tasker. 2002. *Natura 2000*

- in UK offshore waters: advice to support the implementation of the EC habitats and birds directive in UK offshore waters. Joint Nature Conservation Committee, Peterborough, United Kingdom.
- Kelleher, G., and R. Kenchington. 1992. Guidelines for establishing marine protected areas. World Conservation Union, Gland, Switzerland.
- Kelleher, G., C. Bleakley, and S. Wells. 1995. A global system of marine protected areas. Great Barrier Reef Marine Park Authority, World Bank, World Conservation Union, Washington, D.C.
- Kendall, M. S., M. E. Monaco, K. R. Buja, J. D. Christensen, C. R. Kruer, M. Finkbeiner, and R. A. Warner. 2001. Methods used to map the benthic habitats of Puerto Rico and the US Virgin Islands. National Oceans Service, Washington, D.C.
- Kleyer, M., K. Reinhold, L. Gerd, and S. Boris. 2000. Habitat modeling for animal species: development, methods and prospects for their application. *Zeitschrift für Ökologie und Naturschutz* 8:177-194.
- Kramer, P. A., and P. R. Kramer. 2002. Ecoregional planning for the Mesoamerican Caribbean Reef. World Wildlife Fund, Washington, D.C.
- Leslie, H., M. Ruckelshaus, I. R. Ball, S. Andelman, and H. Possingham. 2003. Using siting algorithms in the design of marine reserve networks. *Ecological Applications* 13(supplement):185-198.
- Longhurst, A. 1998. Ecological geography of the sea. Academic Press, San Diego.
- Mace, G. M. 2000. It's time to work together and stop duplicating conservation efforts. *Nature* 405:393.
- Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. *Nature* 405:243-253.
- Mascia, M. B. 2003. The human dimension of coral reef marine protected areas: recent social science research and its policy implications. *Conservation Biology* 17:630-632.
- McManus, J. W. 1994. The Spratly Islands: a marine park? *Ambio* 23:181-186.
- Mumby, P. J., and A. R. Harborne. 1999. Development of a systematic classification scheme of marine habitats to facilitate regional management and mapping of Caribbean coral reefs. *Biological Conservation* 88:155-163.
- Muss, A., D. R. Robertson, C. A. Stepien, P. Wirtz, and B. W. Bowen. 2001. Phylogeography of *Opiblennius*: the role of ocean currents and geography in fish evolution. *Evolution* 55:561-572.
- National Oceanic and Atmospheric Administration (NOAA). 2000. Florida Keys National Marine Sanctuary regulations. Federal Register 65:31633-31680.
- Natural Resources Defense Council (NRDC). 2000. Priority ocean areas for protection in the Mid-Atlantic: findings of the NRDC's marine habitat workshop. NRDC, New York.
- Olson, D. N., and E. Dinerstein. 1998. The Global 200: a representation approach to conserving the earth's most biologically valuable ecoregions. *Conservation Biology* 12:502-515.
- Ong, P. S., L. E. Arfuang, and R. G. Rosell-Amball, editors. 2002. Philippine biodiversity conservation priorities: a second iteration of the National Biodiversity Strategy and Action Plan. Department of Environment and Natural Resources, Conservation International Philippines, University of the Philippines Center for Integrative and Development Studies, and Foundation for the Philippine Environment, Quezon City, Philippines.
- Palumbi, S. R., S. D. Gaines, H. Leslie, and R. A. Warner. 2003. New wave: high-tech tools to help marine reserve research. *Frontiers in Ecology and the Environment* 1:73-79.
- Pauly, D. 1995. Anecdotes and the shifting baseline syndrome. *Trends in Ecology & Evolution* 10:430.
- Pauly, D., V. Christensen, and C. Walters. 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impacts of fisheries. *International Commission on Endangered Species Journal of Marine Science* 57:697-706.
- Pew Oceans Commission. 2003. America's living oceans: charting a course for sea change. Pew Oceans Commission, Washington, D.C.
- Pitcher, T. J. 2001. Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. *Ecological Applications* 11:601-617.
- Possingham, H., I. Ball, and S. Andelman. 2000. Mathematical models for identifying representative reserve networks. Pages 291-306 in S. Ferson and M. A. Burgman, editors. *Quantitative methods in conservation biology*. Springer-Verlag, New York.
- RAMSAR. 1999. Strategic framework and guidelines for the future development of the List of Wetlands of International Importance. People and wetlands: the vital link. Seventh meeting of the conference of the contracting parties to the convention on wetlands. Ramsar Convention on Wetlands, Switzerland. Available from [http://www.ramsar.org/key\\_guide.list\\_e.htm](http://www.ramsar.org/key_guide.list_e.htm) (accessed March 2003).
- Ray, G. C. 1975. A preliminary classification of coastal and marine environments. Occasional paper 14. World Conservation Union, Morges, Switzerland.
- Ray, G. C., and B. P. Hayden. 1993. Marine biogeographic provinces of the Bering, Chukchi and Beaufort Seas. Pages 175-184 in K. Sherman, L. M. Alexander, and B. D. Gold, editors. *Large marine ecosystems: stress, mitigation and sustainability*. American Association for the Advancement of Science Press, Washington, D.C.
- Reeves, R. R., and S. Leatherwood. 1994. Dolphin, porpoises and whales. 1994-8 action plan for the conservation of cetaceans. World Conservation Union Species Survival Commission, Cambridge, United Kingdom.
- Richer de Forges, B., J. A. Koslow, and G. C. B. Poore. 2000. Diversity and endemism of the benthic seamount macrofauna in the southwest Pacific. *Nature* 405:944-947.
- Roberts, C. M. 1998. Sources, sinks and the design of marine reserve networks. *Fisheries* 23:16-19.
- Roberts, C. M., et al. 2003. Application of ecological criteria in selecting marine reserves and developing reserve networks. *Ecological Applications* 13(supplement):215-228.
- Roberts, C. M., et al. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* 295:1280-1284.
- Russ, G. R., and A. C. Alcalá. 1996. Do marine reserves export adult fish biomass? Evidence for Apo Island, central Philippines. *Marine Ecology Progress Series* 132:1-9.
- Sala, E., O. Abuto-Oropeza, G. Paredes, I. Parra, J. C. Barrera, and P. K. Dayton. 2002. A general model for designing networks of marine protected areas. *Science* 298:1991-1993.
- Salm, R. V. 2002. Building survivability into marine protected area networks. South East Asia WCPA-marine workshop: development of a regional action plan to strengthen a network of effective marine protected areas in South East Asia, Bangkok, Thailand. World Conservation Union, Gland, Switzerland. Available from <http://wcpa.iucn.org/biome/marine/seasia/workshop.html> (accessed June 2003).
- Salm, R. V., and J. R. Clark. 2000. Marine and coastal protected areas: a guide for planners and managers. World Conservation Union, Gland, Switzerland.
- Sherman, K. 1993. Large marine ecosystems as global units for marine resources management: an ecological perspective. Pages 3-14 in K. Sherman, L. M. Alexander, and B. D. Gold, editors. *Large marine ecosystems: stress, mitigation and sustainability*. American Association for the Advancement of Science Press, Washington, D.C.
- Spalding, M., F. Blasco, and C. Field. 1997. World mangrove atlas. The International Society for Mangrove Ecosystems, Okinawa, Japan.
- Spalding, M., C. Ravilious, and E. P. Green. 2001. World atlas of coral reefs. University of California Press, Berkeley.
- Steele, J. H. 1985. A comparison of terrestrial and marine ecological systems. *Nature* 313:355-358.
- Sullivan Sealey, K. M., and G. Bustamante. 1999. Setting geographic priorities for marine conservation in Latin America and the Caribbean. The Nature Conservancy, Arlington, Virginia.
- Turner, W., S. Spector, N. Gardiner, M. Fladeland, E. Sterling, and M. Steinger. 2003. Remote sensing for biodiversity and conservation. *Trends in Ecology & Evolution* 18:306-314.

- Turpie, J. K., L. E. Beckley, and S. M. Katua. 2000. Biogeography and the selection of priority areas for conservation of South African coastal fishes. *Biological Conservation* **92**:59-72.
- Udvardy, M. D. E. 1975. A classification of the biogeographical provinces of the world. Occasional paper 18. World Conservation Union, Morges, Switzerland.
- United Nations Department of Economic and Social Affairs (UN/DESA). 2002. Key outcomes of the summit, Johannesburg, South Africa. World Conservation Union, Gland, Switzerland. Available from <http://www.iucn.org/wssd> (accessed December 2002).
- United Nations Environment Program (UNEP). 2002. Mediterranean action plan. UNEP, Geneva. Available from <http://www.unepmap.org/> (accessed December 2002).
- Vecchione, M., and B. B. Collette. 1996. The central role of systematics in marine biodiversity problems. *Oceanography* **9**:44-45.
- von Meyer, N., K. E. Foote, and J. Huebner. 1999. Information quality considerations for coastal data. Pages 295-305 in D. Wright and D. Bartlett, editors. *Marine and coastal geographical information systems*. Taylor and Francis, Philadelphia, Pennsylvania.
- Wikramanayake, E., E. Dinerstein, C. J. Loucks, D. M. Olson, J. Morrison, J. Lamoreaux, M. McKnight, and P. Hedao. 2002. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press, Washington, D.C.
- World Conservation Union (IUCN). 2002a. Red list of threatened animals. IUCN Species Survival Commission, Cambridge, United Kingdom.
- World Conservation Union (IUCN). 2002b. Review of natural heritage sites included in the World Heritage list and tentative lists. IUCN, Washington, D.C.
- World Wildlife Fund (WWF). 2000. The Global 200 ecoregions: a user's guide. WWF, Washington, D.C.
- World Wildlife Fund (WWF) and World Conservation Union (IUCN). 2001. The status of natural resources on the high-seas. WWF and IUCN, Gland, Switzerland.
- Wright, D., and D. Bartlett, editors. 1999. *Marine and coastal geographical information systems*. Taylor and Francis, Philadelphia.
- Zacharias, M. A., D. E. Howe, J. R. Harper, and P. Wainwright. 1998. The British Columbia marine ecosystem classification: rationale, development and verification. *Coastal Management* **26**:105-124.
- Zeman, C. J., and J. H. M. Willison. 2001. International efforts to protect marine biodiversity through marine wilderness preservation in the Northwest Atlantic (New England). *Endangered Species Update* **18**:212-218.
- Zhang, Y., and J. F. Grassle. 2002. A portal for the Ocean Biogeographic Information System. *Oceanologica Acta* **25**:193-197.

