FEATURE:
FISHERIES MANAGEMENT

The Challenge of Managing Nearshore Rocky Reef Resources

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ABSTRACT: Nearshore temperate reefs are highly diverse and productive habitats that provide structure and shelter for a wide variety of fishes and invertebrates. Recreational and commercial fisheries depend on nearshore reefs, which also provide opportunities for non-extractive recreational activities such as diving. Many inhabitants of nearshore temperate reefs on the west coast of North America have very limited home ranges as adults, and recent genetic evidence indicates that the dispersion of the larval stages is often restricted to tens of kilometers. Management of temperate reef resources must be organized on very small spatial scales in order to be effective, offering unique technical challenges in terms of assessment and monitoring. New enabling legislation could assist in specifying mandates and adjusting institutional design to allow stakeholders and concerned citizens to formulate management policies at local levels, and to aid in implementing and enforcing these policies.

El Reto de Administrar Recursos en Arrecifes Rocosos Costeros

RESUMEN: Los arrecifes costeros templados son hábitat altamente diversos y productivos que proveen estructura y refugio a una variedad de peces e invertebrados. Las pesquerías recreativas y comerciales dependen de los arrecifes costeros, que también ofrecen oportunidades para las actividades recreativas no-extractivas, como el buceo. Muchos de los habitantes de los arrecifes costeros en la costa oeste de Norteamérica, poseen estrechos ámbitos de distribución en su forma adulta; la evidencia genética más reciente indica que la dispersión de los estadios larvales muchas veces se restringe a algunas decenas de kilómetros. El manejo de los recursos en arrecifes costeros debe estructurarse y organizarse a una escala muy pequeña para que sea efectivo, lo que plantea un reto único en cuanto a evaluación y monitoreo. La introduccion de nueva legislacion podria asistir a establecer mandatos y disenos institucionales que permitan a los interesados en estos recursos formular politicals locales de maraejo, asi como tambien ayudar a implementar y fiscalizar dichas politicas.

Nearshore rocky reef ecosystems extend from the shoreline to a depth of about 40 m, with most human activities concentrated in areas of rocky reef and kelp forests. Species composition within these ecosystems differs from area to area, but off the West Coast of Canada and the United States the main fisheries resources (Figure 1) are rockfishes (Genus *Sebastes*), greenlings (Family Hexagrammidae), sculpins (Family Cottidae), sea urchins, and abalone (Figure 2). While these ecosystems lie within state jurisdiction in the United States, they provide critical juvenile habitat for species such as yellowtail rockfish (*Sebastes flavidus*), which spend their adult years in federal waters (3–200 miles from the coast), and residents such as black rockfish (*Sebastes melanops*) that migrate across state boundaries.

Because of their high diversity, their critical role as habitat for important fishery species, and their close proximity to coastal development, nearshore temperate reefs present unique management challenges that require cooperation among state and federal agencies. Over 80 concerned citizens and scientists from California, Oregon, Washington, British Columbia, and Alaska gathered in Seattle on 7–8 June 2007 to consider the management of living resources on rocky nearshore reefs within the region. A "Symposium on Managing Temperate Reef Resources" sponsored by the University of Washington School of Aquatic and Fishery Sciences assembled scientists, managers, and stakeholders from federal, tribal, and state agencies; academia; and conservation groups to focus on the emerging problems presented by these resources. They were joined by scientists from as far away as Australia and Argentina.

Symposium panelists and attendees reported that recreational and commercial fishing pressure on nearshore reefs is on the increase both in Canada and the United States, presenting a management problem that is dangerous to ignore. Experience with the rapid expansion of sea urchin (Berkes et al. 2006) and "live-fish" (captured and sold alive at premium prices) fisheries have shown that stocks can go from underexploited to depleted in five years or less. In this era of globalization and rapid change, functional management systems capable of allocation, monitoring, and enforcement must be in place and capable of responding to rapid increases in catches within one year if they are to be effective (Berkes et al. 2006). The costs of delay are high, since many of the species inhabiting nearshore rocky reefs can live half a century or more (Ebert and Southon 2003; Beamish et al. 2006). Rebuilding depleted stocks can take decades, and may not be possible at all (Hutchings and Reynolds 2004). Symposium participants identified key research and management issues that should be prioritized to assure the long-term sustainability of nearshore temperate reef systems: understanding issues of scale and connectivity, integrating state and federal management in a spatially-explicit framework, and instituting locally-based assessment and adaptive management.

RESEARCH CHALLENGES: SCALE AND CONNECTIVITY

Acoustic and conventional tagging long ago established that many adult fish and shellfish inhabiting these reefs range less than 100 square meters over the course of their lives. For many years, it was assumed that these adults were linked over more extensive scales through their dispersive egg and larval stages. However, recent genetic work has shown that in nearshore areas (less than about 40 meters deep), larval dispersion can be very limited (Gunderson and Vetter 2006), and many species conform to a "stepping stone" model (Figure 3). This limited dispersal results from diffusive oceanographic processes that tend to dominate advective processes as one moves shoreward (Largier 2003). Depending on the parameters used in the model, mean larval dispersion over several generations is estimated to range from 1–40 km for the species of rockfish that have been examined to date (Table 1, Buonocorsi et al. 2002, 2004, 2005). Propagule dispersion distances for kelp and some species of abalone are even lower than those in Table 1 (Reed et al. 2006; Morgan and Shepherd 2006). These findings present a new challenge to fishery managers accustomed to managing populations which range more widely over the course of their lives.

Nearshore reefs are home to many juvenile fishes that spend their

Figure 1. Typical nearshore rocky reef fishes of the Northeast Pacific: (a) copper rockfish (*Sebastes caurinus,* Wayne Palsson), (b) male kelp greenling (*Hexagrammos decagrammus,* Wayne Palsson), (c) newly recruited juvenile rockfish in kelp canopy (John Hyde), (d) lingcod (*Ophiodon elongatus*, Wayne Palsson).

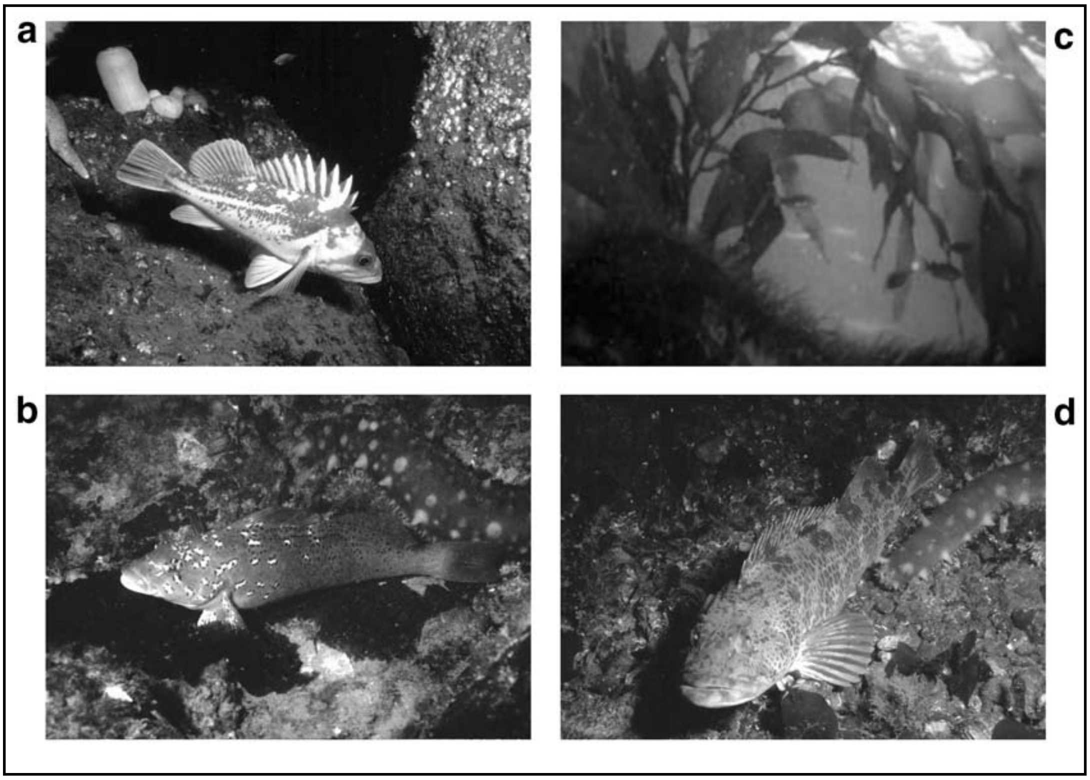


Figure 2. (a) An endangered white abalone (*Haliotis sorensoni*), one of several species of abalone inhabiting nearshore rocky reefs in temperate waters (John Butler), (b) large red sea urchin (*Strongylocentrotus franciscanus*) in an aggregation of smaller purple sea urchins (*S. purpuratus,* Greg Jensen).

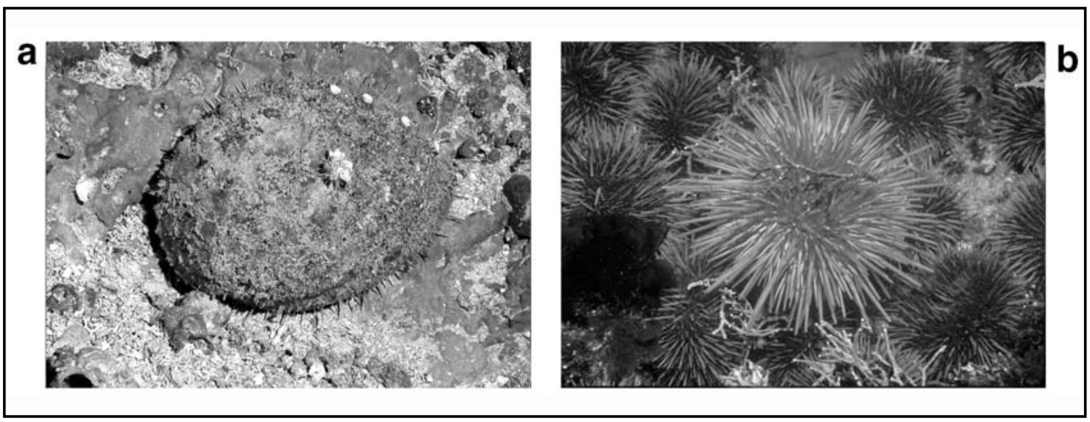
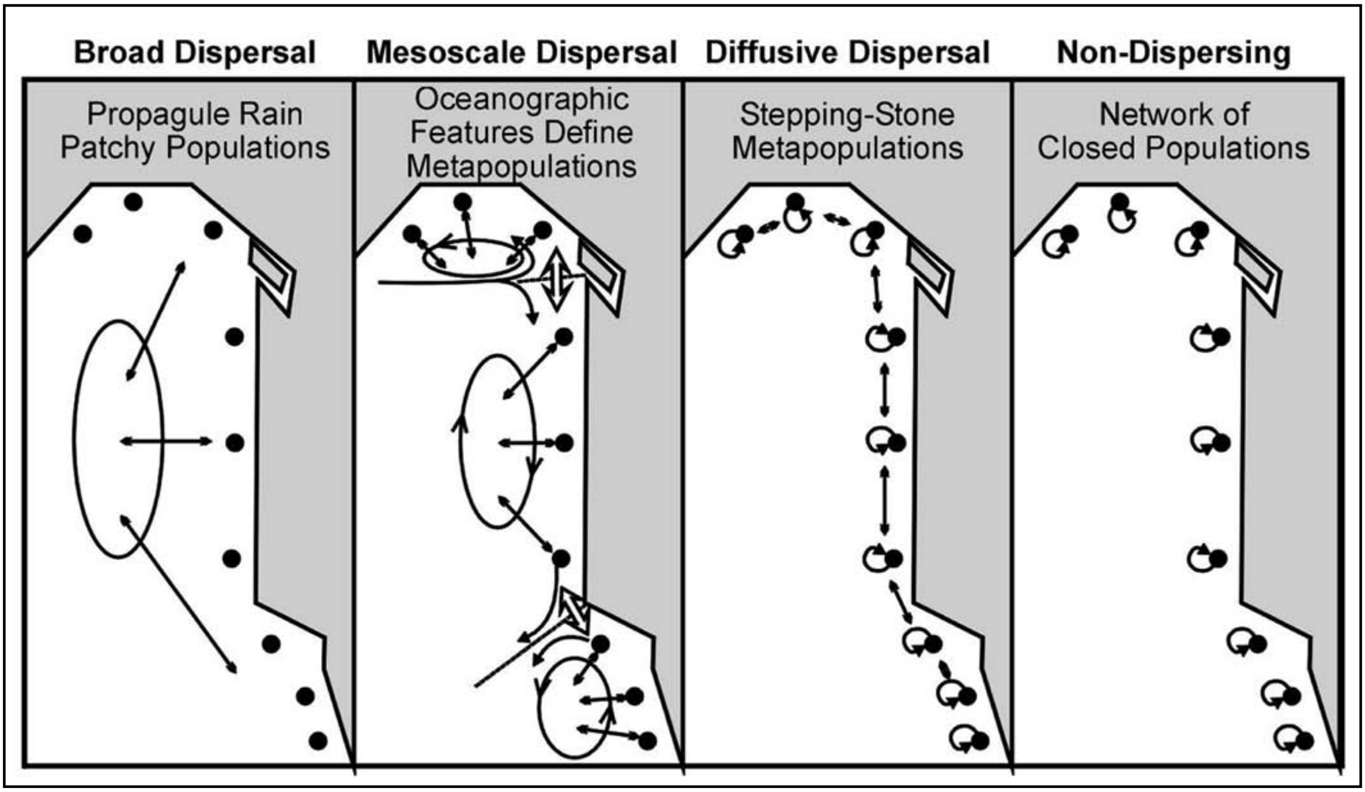


Figure 3. Propagule dispersal models and population structure: (a) broad advective dispersal typical of species with extended early planktonic stages, (b) mesoscale dispersal typical of species whose early life stages develop in the plankton but are retained in an oceanographic feature such as the Southern California eddy, (c) diffusive dispersal typical of nearshore species whose eggs and larvae remain in nearshore boundary layers subject to diffusive rather than advective flows, (d) non-dispersing species that produce large, precocious young capable of swimming and not subject to dispersal by currents (from Gunderson and Vetter 2006).



adult lives in deeper water. Of 25 federally managed groundfish stocks that occur regularly in waters less than 60 m depth, 17 utilize those shallow depths primarily as juveniles (PFMC 2005). Thus, the importance of nearshore temperate reefs for sustainable fisheries may be underemphasized when catch records of adults are the primary source of assessment data. The function of nearshore reefs as nursery habitat requires additional research, and there is very little information available on nearshore-offshore connectivity of populations.

Table 1. Dispersal distance calculations using a stepping stone model, and assuming symmetrical, exponential dispersal along a linear habitat (from Buonaccorsi et al. 2005). Slope of genetic difference between samples ($F_{ST}/(1-F_{ST})$ versus distance apart was determined through linear regression.

	Slope $F_{ST}/(1-F_{ST})$ per 1000 km	Adults per km	s^2	Mean Dispersal Distance (km)
Brown rockfish (*S. auriculatus*)	0.03	10	833	20
	0.03	100	83.3	6
	0.03	1,000	8.3	2
	0.03	10,000	0.8	1
Grass rockfish (*S. rastrelliger*)[A]	0.01	10	2,500	35
	0.01	100	250	11
	0.01	1,000	25	4
	0.01	10,000	2.5	1
Copper rockfish (*S. caurinus*)[B]	0.008	10	3,130	40
	0.008	100	313	13
	0.008	1,000	31	4
	0.008	10,000	3.1	1

A Data from Buonaccorsi et al. (2004)
B Data from Buonaccorsi et al. (2002)

Individual stocks have differing productivity, and their importance to the ecosystem may only be evident when an interdecadal perspective is taken (Hilborn et al. 2003). It is clear that we must either manage nearshore reefs at an appropriately small scale, or run the risk of depleting one stock after another of the more localized populations. Even in cases where larvae disperse more widely, the fact that adults have limited home ranges has implications for monitoring and management, as the status of each reef depends on its own exploitation strategy. If we are to maintain the function and integrity of these nearshore ecosystems, yet take advantage of the economic opportunities and environmental services they provide, a new paradigm for management on smaller spatial scales will be required.

THE NEED FOR INTEGRATED SPATIAL MANAGEMENT

Currently only five geographic areas are used to manage offshore stocks in federal waters off Washington, Oregon, and California. If 10 km segments of the coast are the appropriate unit for management, literally hundreds of units will be required in each state, a situation more analogous to managing a large park or small farm than managing offshore fish stocks. If smaller units are appropriate, the institutional requirements change as well.

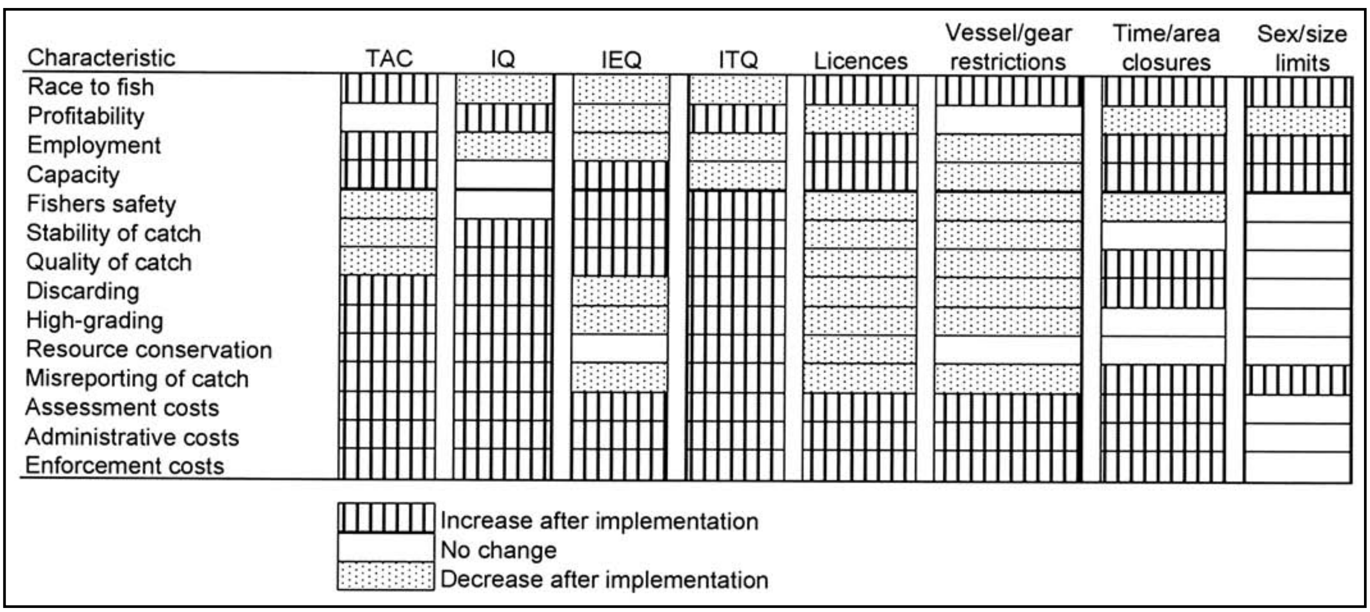
Where ecosystems are the concern, and the goal of managers is to maintain ecosystem function and ensure the persistence of a broad array of consumptive and non-consumptive ecosystem services, the task requires aesthetic and ethical decisions. This is nowhere better characterized than in the differing perceptions of permanent no-take areas. Even the specific labels used can carry emotional baggage among stakeholders with differing aesthetic orientation. Accordingly, networks of no-take areas have been established in California as "Marine Protected Areas" while in British Columbia they are termed "Rockfish Conservation Areas." Some utilitarian stakeholders view such networks as fisheries management tools, while stakeholders oriented toward preservation view the same networks as conservation tools. Clearly, resolving these differences will require zoning for different purposes, and negotiation between stakeholders to arrive at suitable compromises in allocating and managing these zones.

Each zoning plan will need to develop strategies for establishing catch limits within the areas open to exploitation. These should involve different combinations of tactics and also specify the monitoring schemes and feedback mechanisms that will be used to adjust management controls in response to changes in the system. Tactics such as size limits, bag limits, and restricted fishing zones (including no-take zones) or seasons are commonly used in managing recreational fisheries for these species, while trip limits and other catch quotas or (in British Columbia) individual transferable quotas are used for commercial fisheries (Table 2). Each of these tactics has specific advantages and disadvantages (Figure 4), and the combinations selected in Table 2 reflect this. All too often how-

Table 2. Management tactics currently employed in the nearshore fisheries of British Columbia, Washington, Oregon, and California.

Commercial									
Area	Time closure	Area closure	Gear restrictions	Limited access	Gear specs.	Size limits	Protected species	ITQ	Trip limits
BC	X	X				X		X	X
WA		X	X		X		X		X
OR	X	X	X	X		X	X		X
CA	X	X	X	X	X	X			X
Recreational									
Area	Time closure	Area closure	Gear restrictions	Limited access	Gear specs.	Size limits	Protected species	Landing quotas	Bag limits
BC	X	X				X			X
WA	X	X	X		X	X	X		X
OR	X	X	X		X	X	X	X	X
CA	X	X	X		X	X		X	X

Figure 4. Impact of different management tactics on fishery characteristics (after Jennings et al. 2001). TAC: Total Allowable Catch, IQ: Individual Quota, IEQ: Individual Effort Quota, ITQ: Individual Transferable Quota.



ever, these tactics tend to be piled onto one another as managers "chase" the problem of a declining resource (Perry et al. 1999).

ADAPTIVE MANAGEMENT AT SMALL SPATIAL SCALES

The resource management "toolkit" should be expanded to include wider use of adaptive management techniques. The localized nature of many species in the rocky reef community makes it possible to carry out experimental manipulations of relatively small zones to explore ecosystem interactions, and their response to fishing. Such experiments could also make it easier to disentangle the effects of climate and fishing on these ecosystems—always a problem in areas where both impacts operate simultaneously. A rich body of theory indicates that when a large number of experimental areas can be incorporated into adaptive management designs, this can be a powerful tool for informing effective resource management (Walters 1986).

Management must become more localized if it is to undertake adaptive experiments on the appropriate scale, and is likely to depend on stakeholders for the development and implementation of management programs. Experience in British Columbia has shown that enforcement issues such as illegal or unreported catches and high-grading catches to retain only the most valuable individuals are to be expected, and can be addressed most successfully if local residents and stakeholders support the management regime and develop their own solutions to these problems.

Regional approaches could be developed which incorporate local initiatives with strong mandates and responsibilities for management. The task of designing statistically valid experimental programs, monitoring them, and developing decision rules for management will require the assistance of professionals with training in statistics, population, and ecosystem modeling. State, tribal, and federal agencies should provide advice and guidelines for such communities in order to maintain consistency and comparability across regions. The longevities of many rocky reef inhabitants are such that once catches approach sustainable levels, a 5–10 year cycle of experimentation and regional monitoring with scuba and remotely operated vehicles (ROVs; Tables 3 and 4) may suffice, potentially lowering monitoring costs. Habitat maps obtained using multibeam sonar (Figure 5) will aid in identifying and mapping critical habitat, making it possible to pair experimental areas more effectively and conduct stratified random surveys (R. Pacunski, D. R. Gunderson, and H. G. Greene. Washington Department of Fish and Wildlife, Mill Creek, unpublished data) in different habitats. Nevertheless, it is likely that the development of management policy, allocation decisions, and enforcement initiatives will be largely local. Modifications in the legal and institutional structure at the federal and state level will be required to facilitate this.

STAKEHOLDER PARTICIPATION: LOCAL PROBLEMS, LOCAL MANAGEMENT

In a new era where the ecosystem (rather than an individual species) is the focus of management, and non-extractive users assume a more visible profile, new institutions and processes for decision making must be established. These institutions should empower extractive users like commercial and recreational fishermen to interact with citizens interested in scuba diving or underwater wilderness areas to jointly formulate ways of zoning the areas within a jurisdiction in order to achieve specified goals. Some areas could be zoned for commercial exploitation of species like sea urchins, rockfishes, or greenlings, others for recreational fishing or for "watchable" wildlife. The stakeholders who are awarded dedicated rights to a given zone should also be willing to bear the responsibility for managing them properly. Management reference areas should also be set aside, offering scientists and managers the ability to compare and contrast ecosystems in high-use zones with those that are not impacted by human activities.

Additional legislation is needed authorizing localized management of nearshore rocky reefs, whereby groups of stakeholders can be assigned dedicated use privileges for the resources within a given zone as well as the responsibility for managing them properly. There are several successful examples of managing valuable species such as abalone and other shellfish on small scales in Australia, Asia, Europe, and Latin America (Molares and Freire 2003; Makino and Matsuda 2005; Defeo and Castilla 2006; Gonzales et al. 2006), and these usually involve territorial rights for specific areas and species, assigned either to individual fishermen or cooperatives. Once these rights have been assigned, the stakeholders involved have an incentive to take on the responsibility and financial burden of seeing that their resource allocations are managed properly, and they can be highly innovative in managing them. However, experience in Chile has shown that there is a tendency for different cooperatives to use different data collection procedures, and that centralized coordination may be required to ensure consistency over time and space. Incorporating the needs of the recreational fishery also poses a significant challenge to the spatial partitioning of management decisions.

The process of developing enabling legislation for local management, establishing terms of reference for local management entities, and coordinating across state and federal boundaries clearly presents a significant challenge. The management entities that emerge in response to this challenge will be most

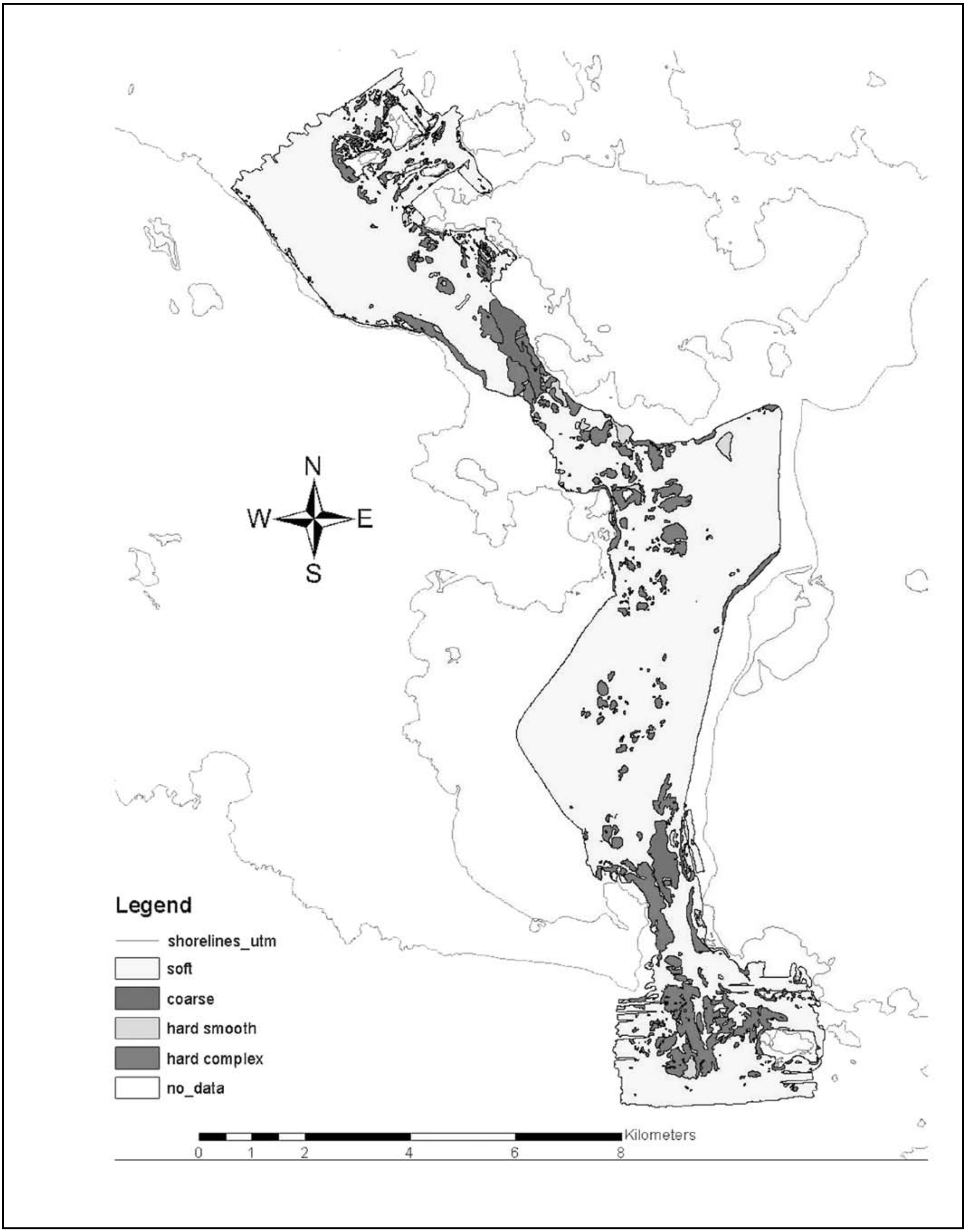
Table 3. Ninety-five percent confidence intervals around population estimates obtained using an ROV in San Juan Channel, Washington (Pacunski et al. unpublished).

Number of Transects (n)	Copper rockfish	Quillback rockfish	Lingcod
Shallow n = 14 Deep n = 11	± 48%	± 93%	±51%
Shallow n = 20 Deep n = 20	±39%	±69%	±43%

Table 4. Number of paired sites required for 95% confidence intervals of a specified range around the mean difference between fished and unfished sites. Based on scuba survey data from San Juan Channel, Washington, Eisenhardt (2001).

Range	Copper rockfish	Lingcod
±50%	15	6
±30%	42	16
±20%	96	35

Figure 5. Simplified potential habitat map of San Juan Channel, Washington, used in a stratified random camera survey with an ROV. Based on multibeam bathymetry, acoustic backscatter, subsequent groundtruthing, and geological classification.

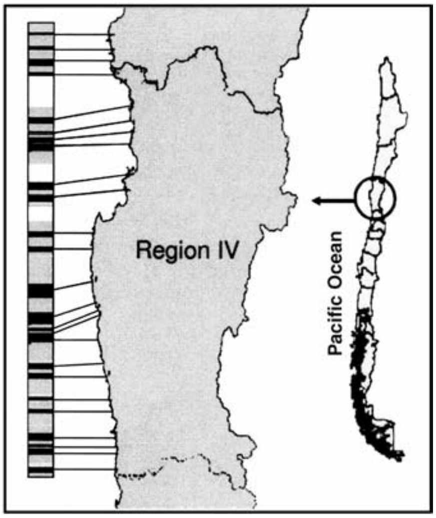


successful if they are designed not only taking into account the spatial scales of the biological resources, but also the patterns of use by different stakeholders and the organizational scales which already exist at the human level. Over 300 territories (Figure 6) have been assigned to local fishers' organizations in Chile to monitor and exploit the "loco" (a high-value mollusk, *Concholepas concholepas*) and other shellfish, taking advantage of the fact that historical fishing zones around individual ports and landing sites have relatively little overlap (Gonzales et al. 2006). The Northwest Straits Marine Conservation Initiative (www.nwstraits.org) in Washington, the Port Orford project off Oregon (www.pmcc.org), and Local Area Management Plans (LAMPs) in Alaska offer three different models of how this might be accomplished in the United States.

The Northwest Straits initiative was authorized by the U.S. Congress to establish and fund county-based Marine Resource Committees (MRCs) in Washington. Each of these county-level MRCs enlists volunteers to select restoration and conservation projects that meet performance benchmarks. They then attract partners from government agencies and conservation groups, and engage citizens in carrying these projects out. Several MRCs have been involved in selecting Marine Protected Areas to aid the recovery of fish populations on nearshore reefs.

The Port Orford Initiative is a pilot project being carried out by the Pacific Marine Conservation Council (PMCC), Port Orford Ocean Resource Team, Surfrider Foundation, and Ecotrust. The overarching goal of the project is to develop a stewardship area that conserves the biological integrity of nearshore reefs while maintaining access to the resource by fishermen utilizing sustainable methods. The project focuses on a specific human community (Port Orford, Oregon) and a specific geographic region (the area surrounding Orford Reef). PMCC, stakeholders, and citizens of Port Orford are developing a stewardship plan which outlines governing principles and performance standards, addresses access and allocation issues, proposes no-take areas for management and scientific monitoring, and incorporates on-board data collection for management and monitoring.

Figure 6. Right: map showing Chile's 12 administrative regions. Left: Region IV showing the cooperatives holding territorial user rights (TURFs). Bar to the extreme left indicates status of segments along the coast: black, TURFs that include loco as a target resource; gray, background segments with suitable substrate, but not incorporated into TURFs; white, segments where substrate is not suitable for loco (after Gonzales et al. 2006).



Enabling protocol for Local Area Management Plans (LAMPs) was introduced in 1998 by the Alaska Board of Fish (BOF) and North Pacific Fisheries Management Council (NPFMC), allowing communities to develop proposals for locally determined fishery management to be implemented if certain guidelines are met (www.sf.adfg.state.ak.us/region2/groundfish/pdfs/guidelines.pdf). Although the Alaska Department of Fish and Game works with groups seeking to develop a LAMP, local users are tasked with the primary burden of plan development, and the board suggests assembling a local advisory committee or task force for this purpose. A LAMP should reflect a high degree of consensus from user representatives in the area, and encompass fisheries for all shared fish stocks in the local area for which conflict exists. The plan should include, as appropriate, catch and possession limits, gear types, effort limitation, closed areas, seasons, and overall boundaries of the local area plan. A Sitka Local Area Management Plan (Springer 2006) was developed to address the issue of halibut depletion in local marine waters and associated user conflicts, and has been approved by the BOF and NPFMC. Additional LAMPs are currently being considered.

THE WAY FORWARD

We are in the beginning stages of developing institutions capable of addressing the challenge of managing nearshore reef ecosystems, and further models can be expected to emerge. Previous experiences in implementing nearshore management programs in California (Mize 2006) and British Columbia (www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/rockfish/default_e.html) have shown that extensive consultation with stakeholders and citizens, and educational outreach will be vital to the success of any institution that emerges. Any successful management framework will no doubt incorporate elements such as:

1. Establishing an appropriate legal management framework;
2. Clearly stating goals and guidelines for management;
3. Stating access rights and incentives that will be used to achieve them;
4. Monitoring and enforcing in such a way that it is clear if goals are being achieved or not;
5. Involving relevant stakeholders and communities in allocation decisions; and
6. Implementing an educational outreach program to inform citizens of the importance of nearshore reef resources and the steps necessary to preserve and manage them effectively.

While these elements are critical to the success of any management program, they need to be instituted in new ways, and at much smaller scales for nearshore ecosystems.

The transition to more localized management may have to be accomplished with little increase in existing public funds. If this is the case, sample sizes per management area can be expected to decline, and the precision of most monitoring and catch reporting data could also decline unless augmented by volunteer efforts such as the Reef Environmental Education Foundation (REEF) diving program (www.reef.org). REEF trains volunteer divers in survey methods and data entry, and maintains a centralized database of their results. While one of the main goals of the program is to develop an index analogous to the Audubon bird census, more statistically rigorous monitoring programs have been developed in conjunction with the National Marine Sanctuary Program.

Simplified decision rules for catch control based on trends rather than absolute abundance, and monitoring based on comparisons of sizes and densities in a representative sample of fished versus no-take areas (Table 4) may simplify data needs for the management systems that evolve. The International Pacific Halibut Commission currently has a data-intensive management program, based on a system of sophisticated population dynamics models, tagging experiments and at-sea surveys. Nevertheless, the commission functioned effectively for years using relatively simple decision rules, catch, age composition, and catch per unit effort data (Southward 1968). However, even simple management programs will require reliable data at small spatial scales, and if volunteer and professional programs fail to provide the data required, management decisions should be suitably precautionary to account for this.

Attendees at the Symposium on Managing Temperate Reef Resources agreed that there are many challenges facing the creation of a new paradigm for locally-based conservation and management of these critical habitats. Nevertheless, the need for cost-effective, holistic approaches also creates an opportunity to promote cooperative research and local stewardship. By combining the knowledge and expertise of biological, physical and social scientists, fishermen and resource users, and state, tribal and federal managers, we can forge a new path that will define ecosystem-based management of nearshore resources.

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