RESCALING FISHERIES ASSESSMENT AND MANAGEMENT: A GENERIC APPROACH, ACCESS RIGHTS, CHANGE AGENTS, AND TOOLBOXES

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ABSTRACT

Small-scale spatially complex fisheries resources present a particular challenge to centralized governmental top-down models of assessment and management. Such processes have an implicit scale and cost that cannot be simply resized to address the complexity, small scale, low unit value, and overwhelming number of these resources. International experience with alternative management systems has produced convergence on a solution to this issue, which involves redesigning the centralized top-down models of data collection, assessment, and management. Central to the solution are governance systems that confer secure exclusive access rights on fishers, so that they have strong incentives to engage in processes of data collection, assessment, and management. I suggest that the next layer of the solution is to recognize the generic nature of the issue and to develop a simpler generic approach that can be locally adapted to each small-scale resource. The generic approach proposed involves (1) the use of barefoot ecologists or change agents trained to work with both the social and biological dimensions of each resource with the aim of creating social capital and empowering local fishers to collect their own data and (2) the design and implementation of simple harvest policies intended to conserve local levels of spawning biomass.

The misfit of both temporal and spatial scales between ecosystems and institutions has come to be recognized as central to the problem of assessing and managing marine and terrestrial renewable resources (Lee, 1993; Hilborn et al., 2005; Orensanz et al., 2005; Wilson, 2006; Folke et al., 2007). Hilborn et al. (2005) suggested that one of the three primary causes for failure in fisheries is the mismatch between the spatial scale of fished populations and the scale of their assessment and management. My focus here is a portion of this broader issue: the assessment and management of small-scale spatially complex fish stocks that centralized forms of management seem particularly unsuited to sustaining (Prince et al., 1998; Berkes et al., 2001; Johannes, 2003; Hilborn et al., 2005; Orensanz et al., 2005; Prince, 2005; Wilson, 2006).

The problems created when fish range across national political borders are obvious, but much less attention has been paid to mismatches that disguise the fine-scale structure of fish stocks (Wilson, 2006). Although fisheries texts have long recommended analyzing fishery data at the finest possible scale (e.g., Gulland, 1969), such resources are usually assessed and managed as though they were panmictic, dispersing freely throughout their ranges (Wilson, 2006). Awareness is growing that many species have complex stock structures (Johannes, 1978, 1981a; Stephenson, 1999; Hilborn et al., 2005) forming metapopulations (Shepherd and Brown, 1993; Wilson, 2006) composed of many small populations or “microstocks” (Prince, 2005) that can be relatively isolated from each other or connected by complex flows of larvae and/or juveniles and adults (Orensanz et al., 2005; Almanny et al., 2007; Temby et al., 2007). Orensanz et al. (2005) term these fisheries “S-fisheries” after the common first letter
of many of the adjectives used to describe them (e.g., small scale, spatially structured, sedentary stocks).

Prince et al. (1998) and Prince (2005) used the Australian abalone (haliotid) fishery as a case study to illustrate why the small scale (10s–100s of meters) of larval, juvenile, and adult movement combined with the variable size of maturity make otherwise effective broad-scale management, with size limits, limited entry, and individual transferable quotas, ineffective and led to serial depletion and the erosion of spatial structure in the stock: at the scale of component populations or microstocks (100s to 1000s of meters) de facto open access continued (Wilson, 2006). The “race to fish” therefore continued within these resources despite broad-scale management limiting fishing mortality at the level of the metapopulation (Wilson, 2006). Terminating this problem the “tragedy of scale,” Prince et al. (1998) argued along with others (Berkes et al., 2001; Wilson, 2006) that the problem cannot be solved by simple rescaling of centralized top-down models of assessment and management, because of their implicit broad scale, the sheer number of “units of stock,” and the associated transactional costs (Fig. 1).

The questions I address here are, first, if the existing orthodox models of centralized and top-down fisheries assessment and management are inadequate for small spatially complex fisheries (Wilson, 2006), what model of assessment and management could be successfully applied and, second, if governments can be persuaded to set up governance frameworks that will foster stewardship of small-scale spatially complex fisheries, how will we meet the massive technical challenge of managing a myriad of microstocks? Here, I propose that the keys to this seemingly daunting situation are to recognize the generic nature of the problem and to develop and apply knowledge, techniques, skills, and tools that are also generic. I propose that, rather than uniquely developing specific approaches to each small-scale fishery, we should be replicating and locally adapting a generic approach involving education, community empowerment and facilitation, and fisher-based programs of data collection, assessment, and local management intended to maintain conservative levels of local spawning biomass.

In forming this opinion I have been influenced by both my own experience and the literature describing the challenges and relative successes experienced with these types of fisheries under alternatives to the centralized top-down management models most of us are familiar with. Only a cursory overview of the literature that I am most familiar with is provided here to provide context; readers wishing to examine this topic in depth are referred to the excellent book on this topic by Berkes et al. (2001).

Johannes (1978, 1981a,b, 1984, 2002) and others (Ruddle et al., 1992; Hickey, 2007) have documented, in the context of the small-scale marine resources of Oceania, the ways in which systems of customary marine tenure, which conferred exclusive access rights to local fishing grounds on fishing communities, often fostered the development of traditional systems of sustainable management and the ways in which, more recently, recovery and strengthening of these traditional systems have improved management, partially repairing the erosion that resulted from introduction of centralized government, new fishing technologies, and access to cash markets (Johannes, 1998a, 2002; Ruddle, 2007). Customary marine tenure and other practices that protected marine resources were also common across much of Southeast Asia and Africa before being eroded by similar influences (Johannes, 1981b; Satria,
In 1994, to counter these trends, the International Center for Living Aquatic Resources Management and the Institute of Fisheries Management, with national partners in Asia and Africa, initiated the Fisheries Co-management Research Project, with the aim of developing strategies and processes for use and adoption by governments, fishing communities, and nongovernmental organizations (Pomeroy et al., 2001). Pomeroy et al. (2001) and Macfadyen et al. (2005) provided analyses of the results of this study and discussed the elements of the individual case studies that have contributed to both success and failure. Both produced a list of prescriptions they found successful in fostering self-management (Table 1). Berkes et al. (2001) also make reference to that body of experience and list the same prescriptions.

Yamamoto (1995), Uchida and Wilen (2004), and Makino and Matsuda (2005) describe the decentralized and, in some respects, innovative Japanese system of fishing cooperative associations (FCAs). The Japanese system has its antecedents in 17th-century traditions, but only in 1948 was it fully recognized under law. The FCAs are responsible for managing access to all the coastal fishery resources within their local jurisdictions, including both sedentary shellfish resources such as clams and mussels, sea urchins and abalone, and shrimp and more mobile species like flatfish, rockfish, mackerel, herring, and pollock. Some 85% (almost 250,000) of Japanese fishers are members of FCAs, and they handle 34% of the Japanese total seafood production by weight, almost 50% by value. Within the locality-based FCAs, members of specific fisheries spontaneously organize themselves into fishery-management organizations on a needs basis, in order to focus on issues confronting their fishery. Although not officially counted until 1988, these organizations have steadily grown in number from around 30 in 1948, when the system came into law, to around 500 in 1962, 1339 in 1988, and 1743 in 1998 (Yamamoto, 1995; Uchida and Wilen, 2004).
Table 1. Convergent solutions for managing small, spatially complex fisheries. Synthesized by the author from previous studies in several different parts of the world.

### Oceania (Johannes 1984, 1994, 1998b)
- Exclusive access rights; customary marine tenure; territorial use rights (TURFs)
- Extension workers trained to collect and use fisher knowledge and to facilitate development of local management strategies by villages
- Dataless management: local fisher knowledge and generalized expert knowledge combined to develop simple management strategies for conserving local levels of spawning biomass

### Japan (Yamamoto, 1995; Uchida and Wilen, 2004; Makino and Matsuda, 2005)
- Local fishing rights recognized by law; TURFs
- Local fishers identifying management issues and addressing them through species- or gear-focused groups
- Governmental structures that harmonize management strategies of local and regional scales
- Local extension scientists

### Southeast Asia (Pomeroy et al., 2001)

**Supracommunity level**
- Enabling policy and legislation
- External change agents

**Community level**
- Appropriately scaled and defined boundaries
- Clearly defined membership
- Group homogeneity
- Participation by those affected
- Leadership
- Empowerment, capacity building, and social preparation
- Community organizations
- Long-term local government support
- Property rights
- Adequate financial resources
- Partnerships and partner sense of ownership of process
- Accountability
- Conflict-management mechanisms
- Clear objectives and defined issues
- Enforcement of management rules

**Individual and household level**
- Individual incentive structure

### Southeast Asia and Oceania (Macfadyen et al., 2005)
- User rights that provide strong incentives for stakeholders to engage
- Recognized local communities of stakeholders
- Leadership and strengthening of community-based institutions to engage with comanagement.
- Local political support.
- Formal legislative backing that codifies and helps to enforce community rules and to resolve disputes

### Chile (Orensanz et al., 2005)
- Systems that provide the right incentives
- Promotion of participation by fishers and other stakeholders
- Spatially explicit and experimental management
- Broader definition of data: recognition of the greater utility of spatially explicit qualitative data than of inexplicit quantitative data
- Requirement of spatially explicit data for participation by fishers
- Use of simple feedback decision rules driven by data (as opposed to mediated by assessment models) to adjust harvest regulations in response to monitoring indices
In contrast to those listed above, the Chilean “caleta” system described by Castilla et al. (1998), Orensanz et al. (2005), and Gonzalez et al. (2006) is a recently constructed initiative, established by law in 1992, for artisanal fisheries. Under it, local organizations of fishers are entitled to claim exclusive access rights to the fishing grounds used by their community and are required to gather data and administer management arrangements. In each caleta, fishers harvest a range of some 50 species; diving for bivalves, gastropods, cephalopods, urchins, and kelp; trapping crabs; and setting baited hooks for hake and pink ling. Although not without weaknesses (Gonzalez et al., 2006; W. Stotz, Universidad Católica del Norte, Coquimbo, Chile, pers. comm.) the caleta system has grown rapidly since implementation began in 1997. More than 250 caletas have formed and successfully established their rights to approximately 36% of the coastline that has historically accounted for about 82% of historic landings, and analyses by Gonzalez et al. (2006) suggest the system is largely succeeding in rebuilding stocks of the most valuable species (loco, Concholepas concholepas Bruguière) within the managed areas. On the basis of their collective Latin American experience, Orensanz et al. (2005) provide a six-point prescription for successfully managing S-fisheries (Table 1).

The above is by no means an exhaustive review of the literature on the case studies mentioned, let alone of the broader body of observational and theoretical work that draws on parallel experience from many other parts of the world. Nevertheless any synthesis of this international experience reveals a strong convergence in thinking about the factors that contribute to the successful assessment and management of fine-scale spatially complex marine resources (Table 1). Here, I attempt first to identify these common elements and then to draw them together into an alternative model of assessment and management. I then present a case study illustrating how these principles are currently being applied in the Australian abalone fishery.

Managing Fine-Scale Spatially Complex Fisheries

Resource Users as the Essential Part of the Process.—The spatial complexity and low unit value of these types of resources preclude central-government-dominated processes of data collection, assessment, and management because of cost and scarcity of government resources (Berkes et al., 2001; Prince, 2003a). Fishers must be engaged and take ownership of the entire process of monitoring, assessing, and managing their resources (Berkes et al., 2001; Prince 2003a); they must become more than just harvesters, data providers, or sources of oral information. As concluded by Gonzalez et al. (2006: 522), “In order to become effective stewards, fishers must participate in the identification of the problems, design and conduct surveys and experiments, gather the information, and understand the results.” Clearly only strong incentives will induce the fishermen to accept these responsibilities.

Governance and Management Systems: Exclusive Access Rights.—The incentive to take on the responsibility of stewardship is created by governance frameworks that create exclusive access rights for fishermen (Johannes, 1982, 1984; Ostrom, 1990; Ostrom et al., 1999; Berkes et al., 2001; Charles, 2001; Dietz et al., 2003; Hilborn et al., 2004; Orensanz et al., 2005). This is a robust and symmetrical principle of fisheries management. Johannes (1982: 259) concluded, “It would be difficult to overemphasize the importance of some form of limited entry...to sound fish-
eries management.” Macfadyen et al. (2005) found marked differences in the success of resource management between countries where exclusive access rights exist and those where they do not. Summarizing the body of empirical experience from differing angles, Jentoft (2000) argued that communities that disintegrate are a threat to fish stocks, whereas Hilborn et al. (2004) proposed that sustainable fishing will occur whenever institutional frameworks encourage participants to behave in a way that is considered optimal for society. Recently Costello et al. (2008) tested this premise quantitatively with a metaanalysis of fisheries managed with individual transferable quotas (ITQs), finding that implementation of catch shares halts, and even reverses, the global trend toward widespread collapse. They concluded that institutional change has the potential for greatly altering the future of global fisheries (Costello et al., 2008). The challenge of devising effective governance systems is therefore a fundamental and primary part of the solution to managing fisheries in general (Dietz et al., 2003), and spatially complex fisheries in particular (Hilborn et al., 2004, 2005), which Dietz et al. (2003) likened to a coevolutionary race.

But does the exact form of exclusive access right matter for spatially complex fisheries? Costello et al. (2008) might be read superficially as suggesting that management with ITQs is the preferred form of access right in all situations, but they note that for ease of analysis they restricted themselves to the one narrow class of access rights and stressed, along with others (e.g., Berkes et al., 2001; Hilborn et al., 2005), the need to match institutional reform appropriately with ecological, economic, and social characteristics so that the form of property rights implemented in each fishery can achieve maximal benefits. Ostrom et al. (1999) observed that the empirical evidence across all forms of common-pool resources shows that no single type of property regime works efficiently, fairly, and sustainably in relation to all resources. Focusing on spatially complex fisheries, Prince et al. (1998), Prince (2003a), and Orensanz et al. (2005) all advocated using territorial use rights (TURFs; Christy, 1982) arguing that the spatially explicit nature of TURF management is particularly suited to fostering stewardship of small-scale spatially complex species. Yamamoto (1995) concluded that the nature of Japanese territorial fishing rights is what has lead fishermen to engage in community-based management. Similarly Johannes, in his body of work, accepts a priori that the customary-marine-tenure systems of Oceania and Southeast Asia, based on exclusive territorial rights, are the best suited for managing artisanal fisheries on spatially complex tropical species. Thus TURFs seem to offer the outline of a system that has been observed to work successfully for spatially complex fisheries throughout Oceania, Asia, and South America, wherever governance provides a stable form of exclusive access right.

Clearly the provision of secure exclusive access rights requires the active support of various tiers of government in enacting enabling policy and legislation and in defining appropriate scales (Pomeroy et al., 2001; Wilson, 2006; Folke et al., 2007), but even if governments can be persuaded to enact the reforms needed, the massive technical challenge of managing a myriad of microstocks remains (Prince, 2003a). Common sense and self-interest can be expected to achieve a great deal within communities of fishers, but in most situations some basic level of fisheries expertise will also be needed. Unfortunately the technical challenge of managing, monitoring, and assessing these resources is proportional to the number of functional units of stock rather than to their size or value (Larkin, 1997; Prince et al., 1998; Berkes et al., 2001; Prince, 2003a; Wilson, 2006). Who is going to do all that local adaptation, facilita-
tion, and basic fisheries science? Certainly not small cash-strapped centralized governments or the universities they fund (Fig. 1). Most countries simply have too many small-scale resources to assess and manage individually and not enough taxpayers to pay for it all (Berkes et al., 2001; Prince, 2003a, 2005; Wilson, 2006).

A Generic Approach.—The key to this seemingly daunting situation is to recognize that fundamentally the knowledge, techniques, skills, and tools needed are generic. In a very real sense all marine resources are similar. The tyranny of scale is universal; only the quantitative parameter values vary, like the rate of reproduction \((h)\), natural mortality rate \((M)\), and the absolute spatial scale of normal dispersion over a life cycle. Assessing and managing spatially complex stocks can therefore be considered a generic issue within any governmental framework designed to foster local management. Rather than uniquely developing specific approaches to each small-scale fishery, we should consider a process of efficiently replicating the same process of local adaption to each new local resource and of the repeated use of similar systems of education, facilitation, data collection, mapping, analysis, assessment, and local management.

So what are the key elements of this generic approach to spatially complex marine resources? Drawn from the collective experience cited above, the generic ingredients are agents of change or extension officers supported with a generic software toolbox, the collection and use of fisher knowledge, collaboration with fishers to collect size and abundance data, a broader definition of data and knowledge, clear management objectives, and simple decision rules aimed at conserving local levels of spawning biomass.

Barefoot Ecologists or Change Agents.—Johannes (1984, 1994) wrote that extension workers are needed to support change and that they should be trained to obtain the information needed to plan and sustain village management strategies on the basis of the practical aspects of local knowledge. Pomeroy et al. (2001) and Berkes et al. (2001) described the importance of a similar role, for workers they called “external change agents,” who provide information to fishing communities, facilitate community dialogue about the management of local resources, and catalyze change. In the Japanese system, the extension role is less one of catalyzing change and is more concerned with supporting ongoing processes. Local extension scientists play a liaison role between the fishing communities and government agencies, helping to provide the linkage between local and regional scales of management and coordinating local scientific programs that inform the setting of total allowable catch and monitoring of stock trends (Yamamoto, 1995; Uchida and Wilen, 2004). Likewise in Chile the TURF system’s scientific consultants play an important role, monitoring resource health and stock status for each TURF and reporting the results on behalf of the caletas to the federal regulators who approve local management plans on that basis or modify regulations where necessary (Gonzalez et al., 2006). Although Gonzalez et al. (2006) observed that Chilean artisanal fishers need to be more active in the decision process and less subservient to consultants and that, for these changes to be possible, fishers must understand the dynamics of their resources and be able to engage in dialogue with consultants and managers (rather than simply being handymen for them).

Berkes et al. (2001) noted that small-scale fisheries need a new set of skills and capabilities, people who can work on the interface among science, industry, and
management. They envisage this role as being filled by a mediator/synthesizer, an objective and knowledgeable third party who can cope with inputs from both scientific/technical and industry stakeholders. Noting the generic and basic nature of the skill set needed for this role, along with the considerable breadth of interest and talents required to span community facilitation, fisher lore, survey design, assessment, and management, Prince (2003a,b) termed this role the “barefoot ecologist,” after the Chinese “barefoot doctor” programs that did so much to raise the standard of community health in China during the 1950s, suggesting that, as with the Chinese barefoot doctor program, barefoot ecologists should where possible be drawn from the fishing communities to which they would return to work. The essence of this role should be to act as a change agent building human capacity (Berkes et al., 2001) and social capital (Dietz et al., 2003), empowering fishing communities to monitor and manage themselves (Berkes et al., 2001; Prince, 2003a,b). In relation to the current role of outside experts in the Chilean caleta system, Gonzalez et al. (2006) suggested revamping the system to provide incentives so that new forms of technical/scientific assistance are developed that more closely approximate the concept of barefoot ecologists.

The Use of Fisher Knowledge.—The barefoot ecologist will inevitably have a pressing need for information (Berkes et al., 2001; Prince, 2003a) about the basic distributional and life-history data needed for initial parameterization of assessment models, the ongoing time series data needed to monitor trends, and the social features in the community that will determine how management evolves. Some of the most important techniques in the barefoot ecologist’s toolbox will therefore pertain to the gathering of information.

In any local situation the major repository of information is the fishers themselves, and the use of fisher knowledge is perhaps the most important tool of the barefoot ecologist (Johannes, 1982; Berkes et al., 2001; Prince 2003a). Like the fish themselves, however, such information is never distributed randomly through the fishing community, so random sampling followed by rigorous statistical analysis of data can yield highly variable and misleading results (Neis et al., 1999; Johannes and Yeeting, 2000); 80% of the fish are generally caught by 20% of the fishers and not without reason. Not all fishers are valuable sources of information; the best are also often the most knowledgeable, and seeking out those who enjoy a high reputation among their own people is worthwhile (Johannes, 1981b). Johannes recommended finding people of high reputation and keeping the interviews flexible (“deliberately unstructured”) so that informants themselves can bring up topics they consider important rather than just being channeled to what the researcher thinks will be important (Johannes and Yeeting, 2000). Neis et al. (1999) calls this approach of using interviews to identify the local experts “snowball sampling,” because the referral process “generates an ever-increasing set” of interviewees. In the way Johannes (1981a) practiced the approach, however, it is probably better referred to as the “kernel” approach, whereby many of the interviews serve only to identify those the fishing community regards as the local experts, and these few remarkable individuals then form the kernel of the process from which most of the information is gained.

From my own experience, a key point to be remembered in collecting and using fisher knowledge is to distinguish clearly between what has been observed and the inferences drawn from those observations. The best fishers are invariably powerful
observers and very successfully use the patterns of behavior they observe to predict where, when, and how to fish, and this ability can invariably be trusted. In contrast, the mechanism inferred as having given rise to the observation can often be flawed. Johannes and Neis (2007) provided a nice example, describing how fishers in Belize told Johannes and other researchers where whale sharks (*Rhincodon typus* Smith) were spawning. When they went to investigate these claims they were able to document for the first time whale sharks feeding on clouds of spawn produced by large aggregations of snapper (Heyman et al., 2001). Until that time scientists had not known that whale sharks could feed on such small particulate foods. The key point is always to test what informants say. For this purpose Johannes (1981b) recommended asking some questions to which the interviewer is already confident of the answer and using the response to test the reliability of the informant.

**Fishing for Knowledge.**—Fisher knowledge is particularly useful for learning about behavior and biology, mapping out distributions over space and time, describing stock structures, and describing broad changes in catch and catch rate and in species and size composition trends over time and space. On the other hand, any barefoot ecologist wishing to assess the status of a local resource is likely to want to establish some means of gathering more quantitative time-series data as a means of monitoring abundance over time in order to work toward at least a semiquantitative assessment to support future management decisions. Again local fishing communities should be considered essential to achieving such aims.

Many fishermen gather their own data in order to study patterns they observe and will readily engage with formal monitoring systems if they take ownership of those systems. Two of the dividends from secure property rights are that, having been saved from the “race to fish,” fishermen have both the incentive to participate in data collection and a level of “spare” vessel and personal time that in the right setting can be direct toward data gathering. Working with motivated fishermen to understand the fishing techniques they employ can often reveal ways in which, for few additional resources, valuable long-term spatially explicit indices of abundance can be gathered. In particular, if fishermen will take the trouble to measure at least a few individual animals on each fishing trip and undertake to provide positional and supplemental data, sophisticated size-based indices of abundance can be developed for little additional work and minimal expenditure.

Two examples illustrate what is possible. In the case of the southern shark fishery in southern Australia, 80% of the gill-net fishing occurs in about 18% of the available fishing grounds. The fishers suggested that they could measure every fish and shark caught in the first shot of each trip, generally a low-catch-rate shot placed fairly blindly into a known productive ground. The fisher observes the catch composition of the first shot and decides where to move the net so that the catch composition might be optimized during the rest of the fishing trip. For the cost of about AUD$30,000, this program can gather data that cost approximately AUD$500,000 to gather through government research surveys. In the case of the South Australian lobster fishery described by Walters et al. (1998), fishermen started by voluntarily agreeing to tag one pot in their 40- to 80-pot allocation and measuring all the lobsters in that pot each day. Later, the fisheries agency temporarily allowed the fishermen participating in research to fish with an extra pot above their legal pot allocation on the condition that they tagged and released all the lobsters caught in that extra pot. This low-cost
project allowed development of spatially explicit indices of abundance based on size-structured catch rates and revealed regional differences in movement, growth, and exploitation rates.

**Dataless Management and a Broader Definition of Data.**—Undoubtedly in some fisheries the prospect for gathering even limited quantitative data will be always be elusive. In such truly dataless fisheries, the types of techniques that Johannes (1998b) called “dataless” must be developed and applied. As Johannes pointed out, managing without data does not mean managing without knowledge, as even in the remotest unresearched areas, the information baseline is by no means zero. Similarly Orensanz et al. (2005) recommended broadening our definition of data and noted that a broad base of spatially explicit qualitative data can often be more useful than a few precise but spatially inexplicit quantitative data. Even when no quantitative data exist, combining the knowledge of fishers with the generalized knowledge of fisheries experts can result in powerful “rules of thumb” and “rapid appraisal” techniques through which diagnoses can be made, allowing management to proceed through a common-sense approach (Johannes, 1998b; Berkes et al., 2001). Most marine-resource experts (scientists and fishers) have learned how to make rapid visual assessment of catches and situations (Berkes et al., 2001). For example, in coral reef management, a green reef flat indicates that algae are overgrowing the corals, suggesting that reef gleaning is depleting populations of grazing invertebrates. In a fishery where adults and juveniles can be recognized visually through size, color, or morphology, catches or populations composed almost entirely of juveniles indicate a risk of growth and recruitment overfishing.

**Simple Decision Rules and Clear Management Objectives.**—Moving away from complete reliance on quantitative data toward using qualitative information does obviously force changes in the approach to assessment and management. A broad realization is growing that, while the problem of overfishing intensifies (Mullon et al., 2005), many of the sophisticated approaches being developed to address overfishing, including harvest policies and quota systems, are being designed to require scientific knowledge, data, and model structures beyond the capability of most fisheries (Walters and Pearse, 1996; Cochrane, 1999). In dealing with paucity of data and the spatial complexity that often exacerbates it, the need arises to reevaluate the overreliance on complex, data-intensive stock-assessment models. In their six-point solution for S-fisheries (Table 1) Orensanz et al. (2005) include the “use of simple feedback decision rules driven by data, as opposed to mediated by assessment models, to adjust harvest regulations in response to monitoring indices.” Echoing the call of Ostrom (2007) to develop diagnostic approaches, we must develop simpler procedures based on simple indicators collected directly from the catch.

**Conserving Local Levels of Spawning Biomass.**—Fisheries management can have many objectives and be gauged against many reference points (Berkes et al., 2001), but Johannes (1998b) suggests that the simple objective of dataless management should be conserving precautionary levels of spawning biomass. My own experience leads me to support Johannes’ suggestion strongly for a number of reasons: First, the objective of conserving spawning potential is easily understood and naturally supported by fishers because obviously “without breeders there can be no young.” Second, in the case of fisheries truly without data, the objective is relatively
easily translated into simple management prescriptions for preserving local levels of spawning biomass such as banning the fishing of spawning aggregations or leaving abalone and trochus shells on reef tops to age (and breed) for several years before harvesting. Third, reducing fishing pressure so that exploited species are allowed several years of adult reproduction commonly produces significant gains in yield per recruit for a fishery and can provide rapid positive reinforcement for fishing communities fostering a culture of proactive management. Fourth, where rudimentary forms of data exist, assessing levels of spawning-potential ratio (SPR), the ratio of spawning per recruit for the fished population to the spawning per recruit in an unfish population (Mace and Sissenwine, 1993; Walters and Martell, 2004), combined with rudimentary indices of abundance, can provide a relatively simple and robust form of assessment and the basis for simple harvest strategies and decision rules (Berkes et al., 2001).

Orensanz et al. (2005) raise a valid concern about the “tragedy of the larval commons,” in which upstream sources of larvae are depleted to the detriment of downstream sink populations. Their concern is that incentives for conserving resources within a TURF may be weakened by the constant replenishment of a locally overexploited stock from outside sources (Orensanz et al., 2005), but this difficulty should be avoided by universal adoption of a strategy under which local fishers preserve conservative levels of spawning in all local populations. If the default assumption is changed to one of localized recruitment, and conservative levels of spawning (40%–50%) are maintained in each component population within a metapopulation, normal patterns of flow of individuals through the metapopulations can reasonably be assumed to continue, and the distinction between sources and sinks will become less obvious.

A Generic Software Toolbox.—Inspired by watching the way practitioners of Adaptive Environmental Assessment and Management workshops (Holling, 1978; Walters, 1986) have used a software toolbox to analyze resources as diverse as the Florida Everglades and the Western Australian rock lobster fishery, and building on the idea that the technical needs of spatially complex fisheries are generic, Prince (2003a,b) proposed that barefoot ecologists should be armed with a generic toolbox in the form of a laptop computer equipped with the software they need for any situation. This suggestion has also been made by others working on this issue (e.g., Berkes et al., 2001).

The preceding discussion and supporting literature indicate the basic functions required of such software: (1) mapping, of fishing grounds, catch, effort, size, and patterns of SPR; (2) a database for capturing, storing, and accessing spatially explicit time-series data, catch, area swept, effort, size, growth, and breeding studies; (3) modeling and assessment routines; (4) a highly graphic user interface for visualizing and translating assessments, analyses, and simulations for stakeholders, managers, and researchers; (5) remote access to the global literature so that default parameter estimates are always available from similar species elsewhere in the world (Berkes et al., 2001).

Visualization of the results of resource modeling has tended to be neglected. Models with easy-to-use and understandable graphical output are rare because resource modelers and biologists internally visualize much of their own analysis and have little personal need to represent their data visually (Walters et al., 1998), but
where engaging the understanding and enthusiasm of local stakeholders is critical (Berkes et al., 2001), the power of visualization should not be ignored (Sluczanowski et al., 1992). Moving color pictures provide a powerful form of data compression. Previous applications have demonstrated that presenting population dynamics in interactive moving color graphics makes complicated stock assessment immediately intelligible (Sluczanowski, 1994; Sluczanowski and Prince, 1994; Walters et al., 1998). With reference to one such application Walters et al. (1998: 383) noted that fishers participating in the workshops “were quick to appreciate how the data they collected were used to develop an understanding of such complex and dynamics systems. The power of this type of graphical interface for communicating results was clearly obvious to every biologist in attendance.”

The vision is to develop the toolbox software as an open-source project and to train barefoot ecologists in the use of the same standard generic piece of software. Then, paralleling the process described by Berkes et al. (2001), each time a barefoot ecologist engages with a new marine resource, the process of developing a new adaptation of the software is the same: (1) Mine the international literature for what is known about parallel resources. (2) Find and talk to the best local fishers. (3) Use all available knowledge and proxy parameters from the global literature to fill the gaps in the data needed to adapt the software locally, and produce an interactive, moving color graphic depiction of the local resource. (4) Use the visualization to facilitate discussion and learning in stakeholder workshops, cement understanding of resource processes, and work to galvanize group action. (5) Set up information-gathering systems and start accumulating time-series information. (6) Discuss local management and develop understandable and supportable decision rules for using new information that becomes available through cooperative information gathering.

Each local installation of the software would stay permanently in place, belonging to the local fishers rather than to the barefoot ecologist. The software would contain maps showing their stocks and survey systems, complementary sheets for entering the fishery and survey data collected by the fishers, and the latest fitting of the model accessible as an interactive visual computer simulator. Over time, with the accumulation of reliable time-series data, models of the resource could become more sophisticated and accurate, and simulations of future stock levels should become more reliable. Sluczanowski (1993) saw each local adaption of the software as becoming highly valued by stakeholders over time as their data accumulate and as simulations of catches and cash flow become more accurate. In effect the locally adapted software is left in place to become the ledger for the communities’ business—fish stock accounts (Sluczanowski, 1993).

In this way, approaching the issue of fine-scale complex fisheries as a generic issue might turn the sheer magnitude of the task before us from a weakness into a strength (Fig. 2). The case study that follows illustrates how simple decision rules (Orensanz et al., 2005) or diagnostic approaches (Ostrom, 2007), can be applied to simple forms of spatially explicit information collected by fishers. It also illustrates how engaging fishing communities in their own structured processes of local assessment can lead to improved management without rigorous quantitative assessments and to improved collection of spatially explicit data without increased research budgets.
A Case Study: The Reef Scale Assessment of Australian Abalone Stocks

The Australian abalone fisheries are managed across the jurisdictions of five separate states (New South Wales, Victoria, Tasmania, South Australia, and Western Australia). Each jurisdiction supports several regional fisheries, known as zones, each of which comprises several hundred kilometers of coastline. Across states and zones, management regulations have evolved along parallel paths over four decades, as described by Prince and Shepherd (1992). Generally, 15–40 divers share access to several hundred kilometers of coastline in filling their ITQs while observing some zonal legal minimum length regulations. Under the existing Victorian Abalone Fishery Management Plan (Fisheries Victoria, 2002), fisheries assessments are conducted annually by an Abalone Fishery Assessment Group. This group includes participants from all major stakeholder entities. A keystone of the regional assessment process is the prescribed use of a quantitative fisheries model of each zone to estimate the risk of reducing abalone biomass below zone-specific reference values corresponding to alternate levels of harvest (Gorfine et al., 2001). The Abalone Fisheries Committee, a subcommittee of the Fisheries Co-management Council, is charged with using these results from formal Abalone Fishery Assessment Group workshops to formulate independent advice about future zonal total allowable commercial catches (TACCs) that is communicated through the comanagement council to the Minister for Primary Industries (Fisheries Victoria, 2002). Ultimately, the minister uses this advice in determining the annual TACC for each zone.

The ecology of abalone has important implications for their assessment and management (Prince, 2004, 2005). The small scale of the self-recruiting populations and the differences among populations of size at maturity make assessment and management extremely complex. Zonal minimum lengths and TACCs fail to protect component populations with relatively larger sizes at maturity, so these populations may experience localized recruitment overfishing. Conversely, nearby abalone pop-
ulations with relatively smaller sizes at maturity might remain virtually unfished. The need for more spatially explicit assessment and management of abalone fisheries was identified more than a decade ago (Prince and Shepherd, 1992; McShane, 1995; Prince et al., 1998), but attempts to model the fishery at reef scales have been impeded by the lack of sufficient detailed spatial data.

Since 2001, an industry initiative has been developing an alternative approach to assessing and managing this spatially complex fishery that uses principles of rapid visual assessment (RVA), decision rules, and harvest policies (Prince et al., 2008). The approach is novel in its use of qualitative morphometric markers (shell shape and appearance) to gauge fishing pressure at the scale of abalone reefs and because the local industry associations assess component populations and form and implement prescribed reef-scale harvest policies. Harvest policies are being implemented with reef-scale voluntary minimum length limits and voluntary capping of catches from reef-scale areas so as to distribute the TACC set by government regulation for broad regions of the fishery. In a reversal of the normal “top-down” approach to management, this process of reef assessment by industry is increasingly being used to inform the fisheries agency of the state government during the process of setting regional TACCs.

Central to the RVA technique is the proposition that the relative maturity of abalone can be gauged visually by the shape and appearance of their shells. The use of shape and appearance in fisheries assessment and management is not entirely novel. Morphometrics are used to distinguish between finfish stocks (Begg et al., 1999; Swain and Foote, 1999; Cadrin and Silva, 2005), and Hickey (2007) records that villagers in Vanuatu place taboos on picking turbo shells (*Turbo* spp.) without encrusting growth as a way of protecting immature shells from collection. Juvenile abalone live cryptically in the interstitial spaces within reefs, and as subadults they emerge to join adult feeding and breeding aggregations on the surface of the reef (Prince et al., 1988). Maturity and timing of emergence from the cryptic juvenile habitat are principally determined by age rather than size (Shepherd and Laws, 1974; McShane, 1991; Nash, 1992), and predictable changes in the shape and appearance of abalone shells coincide with these processes (Prince et al., 2008). Juvenile growth is primarily in shell length rather than weight. Before maturity, because juveniles remain wedged in dark interstitial reef spaces, little if any epibiota colonizes the surfaces of their shells. Thus juveniles and newly emerged maturing abalone can be recognized by shells that are flat, oval, and relatively clean of epibiotic growth. In subadults, linear growth slows while rapid growth in total weight continues. Shells both widen relative to their length and become relatively deeper, taking on an increasingly bowl-like shape (Fig. 3). The result is an increase in both the ratio of width to length (Worthington et al., 1995; Worthington and Andrew, 1998) and that of height to length (Saunders et al., 2008). On the surface of the reef, as the abalone mature, their shells become covered with the epibiota typical of the reef as they approach their maximum potential SPR.

**Rapid Visual Assessment of Abalone Reefs.**—Recognizing the coincidence between emergence and sexual maturity in abalone and understanding how shell shape changes with maturity and emergent living provide a powerful, if somewhat crude, tool for gauging the status of abalone populations and developing reef-scale harvest policies (Fig. 3). Taken at its simplest, the RVA technique and the associated reef-scale harvest policies are concerned with identifying populations that consist
almost entirely of abalone with clean, flat, oval shells, which are predicted to have low SPR and to be at risk of growth and recruitment overfishing. The objective is to manage each population in a way that moves it toward consisting principally of individuals with rounded, domed, fouled shells, which, because they are approaching the asymptotic length of the population, are likely to have produced approximately 50% SPR, a biological reference point recommended for abalone by Shepherd and Baker (1998), which should preserve conservative levels of reproductive capacity. This objective of RVA is still based on a relatively qualitative understanding of abalone stock-recruitment relationships, growth, and morphology, but the approach is stimulating a body of research aimed at testing and refining the quantitative basis of the approach (e.g., Saunders et al., 2008; Saunders and Mayfield, 2008). In practice the objective of RVA gains strong support from the abalone divers in each new area to which it is introduced, because they benefit from a rapid gain in yield per recruit when management moves a reef from carrying mainly abalone with clean, flat, oval.
shells to one carrying large numbers of rounded, domed, fouled shells (Prince et al., 2008).

By means of the principles of RVA, any abalone population can be assessed visually through the examination of shells or, more remotely, by extension through commercial divers’ knowledge. Abalone shells from a reef can be sampled from commercial catches or inspected in situ and examined with regard to three primary metrics. First, the size of maturity and emergence can be ascertained from measurements of individuals with clean, flat shells. Next, the size of full maturity and approximately 50% SPR can be gauged from measurements of individuals with rounded, bowl-like shells and surface fouling like that on the reef top. Third, the overall size distribution of the sample can be gauged relative to the size of first maturity, 50% SPR, and the legal minimum lengths. With the RVA technique, and the input of divers, 100s of kilometers of abalone-carrying shoreline can be rapidly assessed over 5–10 d of interviews or during several days of reef-assessment workshops facilitated by the decision tree in Figure 4. Divers who depend on their powers of observation and memory of reefs to fish efficiently readily learn the shell features used to appraise reefs. We have also found that teaching the underlying principles to abalone divers is extremely effective in motivating them to engage with the process of reef-scale management.

**Figure 4. Decision tree for abalone used in reef-assessment workshops to apply rapid visual assessment principles in the development of management plans for individual abalone reefs. Reproduced from Prince et al. (2008).**

The Reef Assessment Decision Tree.—The logic underpinning the process of RVA has been codified into a decision tree (Fig. 4) for use during reef-assessment workshops attended by quota owners and divers of a management zone. The use of the decision tree has facilitated discussions and made the decision-making process more transparent, thus increasing the communal support required for industry associations to initiate voluntary action at reef scales. The decision tree is used to place every reef into one of eight exploitation categories, each of which has an associated
preagreed harvest policy. The primary indicators used to assess the reefs are reef-scale effort and catch trends over the previous 5–15 yrs and the appearance of the abalone shells either on the reef or in the catch. In practice, sufficiently fine-scale effort and catch data are not always available, but we have found that groups of divers can reliably provide qualitative reports on whether effort and catch trends on a reef have been rising, falling, or stable. The first two levels of decision are based entirely on effort or catch trends (Fig. 4). First, trends are identified as either unstable or stable. At the second level, stable trends are classified as either comparatively low or comparatively high, and unstable trends as declining or rising. Shell appearance is then used to distinguish population status further (Fig. 4).

**Development of the Reef Assessment Process.**—The reef assessment workshops began in 2002, when first the Western Abalone Divers Association (WADA, the industry association for the Victorian Western Zone) and then in 2004 the industry association (VADA) of the adjacent Central Zone engaged an “external change agent” to develop with them the basic methodology and then initiated a process of reef assessment and management using the decision tree described above (Prince et al., 2008). The associations now hold two reef-assessment workshops each year to assess data from the previously finished year and to reassess reefs and prepare reef-scale harvesting plans. The associations use the workshops to agree on voluntary size limits and catch levels for each reef so that the total allowable catch is distributed optimally around their zone rather than focused on particular reefs. To help facilitate the associations’ self-management processes, Fisheries Victoria has adapted their quota-reporting system so that it operates in real time. As divers land and weigh their daily catches, they use mobile telephones to report the weight from each reef to an automated system. The progressive catch total for each reef then becomes immediately available on a Fisheries Victoria website. Divers and the executive office of the industry associations can track progressive daily catches to guide selection of future diving locations. The executive officers consult their executive committees when voluntary catch caps are reached on any reef, and divers are notified by e-mail and telephone when the associations voluntarily close reefs.

In recent years both WADA and VADA have concluded that zonal assessment models are overoptimistic and have requested, and been given, TACCs 24% and 19%, respectively, lower than those supported by the zonal models. Both zones have used the catch reductions to implement temporary closures or substantially lower catches from specific reefs that their reef-assessment processes have identified as being of most concern.

In July 2005, Australia’s federal government principal fisheries R&D fund granted four years of funding for continuing reef-assessment workshops with WADA and VADA and extended them to three additional zonal abalone associations: the final zone of Victoria, the New South Wales industry association, and the South Australian Central Zone association. Almost all the other regional abalone industry associations across Australia have also expressed interest in applying the approach. Because the approach is still based on a largely qualitative understanding of abalone fisheries biology, several quantitative studies have also been supported by funding bodies with the aim of testing and refining it. To date the results of these studies confirm the basic validity and effectiveness of the approach (Saunders et al., 2008; Saunders and Mayfield, 2008). Before this quantitative confirmation of the approach,
the support of collaborating agency scientists and managers had still been growing because of the increased understanding they themselves had developed through the reef-assessment workshops. The access to the detailed spatial knowledge of the divers afforded by the workshops has enabled them to understand the resource more clearly and to become more confident of local assessment and management outcomes than they are of the regional quantitative assessments. On the strength of the broad industry interest in the approach, Australia's main funding body has indicated that it is prepared to continue funding the development and extension of the approach over decade-long time frames and has requested assistance in incorporating the approach into its broader R&D strategy.

By engaging industry directly, this approach to assessing and managing a spatially complex fishery is starting to overcome limitations on data collection. Invariably as new industry groups engage with the principles underlying the RVA of reefs and begin making decisions at the scale of reefs based on whatever data are available, they become increasingly interested in gathering better spatially explicit catch and size information for themselves. Generally, each group starts deeply antagonistic to collecting spatially explicit data because of their natural resistance to close monitoring, but in the course of the process, they become increasingly supportive of gathering data for their own use and move to initiate data-gathering programs. This growing interest has promoted development and deployment of technologies that incorporate global positioning systems into collection of spatially explicit size, catch, and effort data. In the Western Zone of Victoria, WADA is now collecting a GPS position, time stamp, and size for every abalone taken, and VADA, one of whose members developed the measuring machine, began deploying the machines in 2002 on a voluntary basis with a subset of divers and collected its millionth measurement in 2007. To support this voluntary program, VADA gives a carton of beer to divers and their deckhands in return for every 10,000 data records.

In its current form, the abalone decision tree and the RVA of an abalone reef are basically qualitative or semiquantitative at best. Some might argue that a more quantitative approach is preferable and ask about species that do not present the handy visual markers used for abalone. Where the fishers can be engaged in collecting size, catch, and effort data, relatively simple assessment-decision trees can be constructed to adjust local catches incrementally until local targets based on SPR and relative abundance are achieved (Campbell et al., 2007). Multiple assessments of this nature across a metapopulation could provide the basis of a scale-less stock assessment and inform local fishing communities about the exploitation rates being experienced by local resources.

Conclusions

Recognition is growing that fine-scale spatially complex fisheries resources present a particular challenge to the centralized top-down model of assessment and management (Berkes et al., 2001; Johannes, 2003; Hilborn et al., 2004; Orensanz et al., 2005; Prince, 2005). A tyranny of scale results from the implicit scale and cost of the top-down processes of central government, which cannot be simply resized to address the complexity, small scale, low unit value, and overwhelming number of component populations that comprise these resources (Prince, 2003a, 2005). Recognizing the misfit between institutional and ecological scales is a necessary first step toward
addressing this issue, but the solution involves redesigning our model for data collection, assessment, and management (Berkes et al., 2001; Prince, 2003a, 2005). Examination of the literature on this topic reveals that international experience with alternative management systems has produced a convergence of thinking about the solutions to this issue. Central to the solution are governance systems that confer secure exclusive access rights on fishers (Johannes, 1982, 1984; Ostrom, 1990; Ostrom et al., 1999; Berkes et al., 2001; Charles, 2001; Dietz et al., 2003; Hilborn et al., 2004; Orensanz et al., 2005) and therefore give them strong incentives to exercise stewardship over their resources and to engage with processes of data collection, assessment, and management, commonly thought of as the responsibility of central government (Berkes et al., 2001; Prince, 2003a; Orensanz et al., 2005). Spatially explicit forms of access rights such as TURFs seem particularly apposite for fostering stewardship of small spatially complex fisheries.

Here, I have argued that the next part of the solution is to recognize that the needs of small-scale spatially complex fish stocks are generic and that a generic approach should be developed for local adaptation to each resource. The generic approach proposed revolves around the use of barefoot ecologists, extension workers or change agents trained to work with both the social and biological dimensions of each resource to create social capital and empower local fishers to collect data and to make their own assessments and management plans. To accomplish these tasks, barefoot ecologists must be equipped with a generic set of skills and a toolbox. An essential skill is the collection and use of fisher knowledge, as exemplified by the body of Johannes’s work cited above. This skill, together with a level of ecological “common sense” can provide the basis for both an initial assessment of a resource and the design of simple data-collection and decision-making systems. Incorporating Johannes’s (1998b) ideas for dataless management and Orensanz et al.’s (2005) recommendation to use simple data-driven decision rules, I recommend adopting the default assumption that recruitment is localized until proven otherwise and designing simple harvest strategies and decision rules based on conserving local levels of spawning biomass.

Acknowledgments

I thank the steering committee of the Seventh Florida State University William R. and Lenore Mote International Symposium for their generous invitation to present this paper. My gratitude also goes to C. J. Walters for many years of tuition, inspiration, and mentoring, in addition to his constructive critique of this manuscript. Thanks also to F. Berkes for extremely helpful comments and directions.

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Available Online: 26 February, 2010.

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