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BEYOND BAND-AIDS IN FISHERIES MANAGEMENT: FIXING WORLD FISHERIES

Ray Hilborn, André E. Punt, and José Orensanz

ABSTRACT

Although existing fisheries management systems have largely failed, the public and most scientists believe this failure is due to overfishing and that the solution includes the precautionary approach, marine protected areas, and ecosystem management. We argue that the existing interpretations of ecosystem management have proved disastrous for the U.S. West Coast groundfish fishery; that no obvious social and economic goal is associated with these interpretations; that maximization of total ecosystem yield would probably perpetuate overfishing on some stocks; and that "weak-stock" management will lead to major losses in potential yields. Although smaller-scale spatial management could prevent overfishing on weak stocks while allowing fishing of healthy stocks, ecosystem management and other biological remedies fail to recognize the real problem: overcapitalization and the race for fish; the "solutions" commonly identified actually treat a symptom rather than the problem. Solutions do exist and have the common characteristic of changing the incentives to make what is good for an individual or group good for society. Examples already in place include community ownership of fishing grounds, cooperative fisheries, and rights-based fishing (e.g., individual transferable quotas).

Although existing fisheries management systems are widely recognized to have largely failed (e.g., the oft-quoted statistic that 33% of U.S. fish stocks are overfished or depleted; NMFS, 1999), the public and almost the entire scientific community believe that this failure is due to overfishing (e.g., Botsford et al., 1997; Costanza et al., 1998; National Research Council, 1999). The solutions generally proposed are "precautionary" reductions in catch limits, "ecosystem management," and the establishment of marine reserves (National Research Council, 1999).

Here, we identify three alternative approaches to the calculation of ecosystem-based catch limits and explore two of them (extensions of single-species models) using the U.S. West Coast groundfish stock as a case study. We argue that overfishing is a symptom of poor governance systems rather than the structural disease to be treated and illustrate this point with examples of failures and successes in fisheries management. We conclude by proposing and discussing a hypothesis: sustainable fishing will occur when the institutional framework encourages the participants to behave in a way that is societally desirable.

Ecosystem-Based Management.—Ecosystem management has remained an elusive concept that can mean vastly different things to different people. Given that fisheries management consists primarily of regulating harvesting through restrictions on time, area, gear, and total allowable catch, how can concepts of ecosystem management be translated into specific fishery regulations? At present, the dominant approach seems to be largely qualitative: to discuss the ecosystem impacts of the fishery within the single-species stock-assessment paradigm and to modify the recommended single-species management regulations on the basis of identified concerns. Although this approach may be the most pragmatic one at present, a number of alternative approaches to calculating "ecosystem-based" catch limits could provide the first step toward true ecosystem man-

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agement. Each of these comes from a somewhat different paradigm of values and views of ecosystem behavior. These alternative approaches include:

(1) Maximizing yield, including trophic interactions. Various models, including Ecosim (Walters et al., 1997, 2000), multispecies virtual population analysis (see, e.g., Stokes, 1992; Magnusson, 1995), and others (see, e.g., Schweder et al., 1998), could be used to identify the fishing plan that maximizes biological or economic yield from a mix of species. Using Ecosim some (C. Walters, Fisheries Centre, University of British Columbia, pers. comm.) have suggested that the policy that produces maximum sustainable or economic yield is often to fish predacious species heavily to increase the total production of a few highly valuable species. Many of the results from multispecies virtual population analysis lead to a similar conclusion—sustainable harvest rates are higher than implied by single-species models when trophic interactions are considered. The value associated with this approach is to maximize sustainable human benefits, which appears to be close to the underlying objectives stated in fisheries legislation in the U.S. and many other countries. It should be noted that, if economic profits rather than biological yield were maximized, the recommended policies would normally involve lower levels of fishing effort and higher stock sizes than policies that maximize biological yield or landed values, because the value of top predators tends to be greater than that of highly variable prey species.

(2) Maximizing the sum of single-species benefits. The maximum yield from the ecosystem could be calculated by means of single-species models with no trophic (biological) interactions but that include fishery (technical) interactions, as the sum of single-species benefits. The value associated with this approach would again be to maximize sustainable human benefits. Below, we provide an illustrative example of how this approach could be used in the U.S. West Coast groundfish fishery. Unlike the previous approach, this one has the advantage that the data needed to conduct the calculations are already available and the results relatively robust to model structure uncertainty (Butterworth and Punt, 2003).

(3) Manage to preserve all species at a level that will produce single-species maximum sustainable yield (MSY). This (single-species) approach, commonly called "weak-stock management" in salmon and groundfish management circles, involves regulating fisheries to prevent any stock from becoming overexploited, or at least to set in place fishing restrictions to allow rebuilding of all overexploited species. This is the de-facto approach implied by the current fisheries management framework in the U.S. It is not clear what objective guides this policy—it is clearly not to maximize economic or yield benefits from the fishery.

(4) Modifying the economic structure of the fisheries to cope better with changes in ecosystem structure and expanding the model used to provide management advice to include a broader concept of "ecosystems." Doing so would involve expanding the concept of "ecosystem" to include fishing communities, markets, economics, and the political system that manages the fishery. Although fisheries are clearly composed of a complex of human and nonhuman components, few regulatory structures include explicit consideration of the social components of fishery ecosystems. The collapse of groundfish in eastern Canada is well known, as is the cost of the long and expensive program of annual government grants (CDN$ one billion; Hilborn et al., 2001), but as groundfish declined, crab and lobsters increased (perhaps as a trophic response, perhaps not), and the increase in their value more than compensated for the loss of income from groundfish (Fig. 1). Few realize that the "ecosystem" yield from the fishery in eastern Canada was hardly

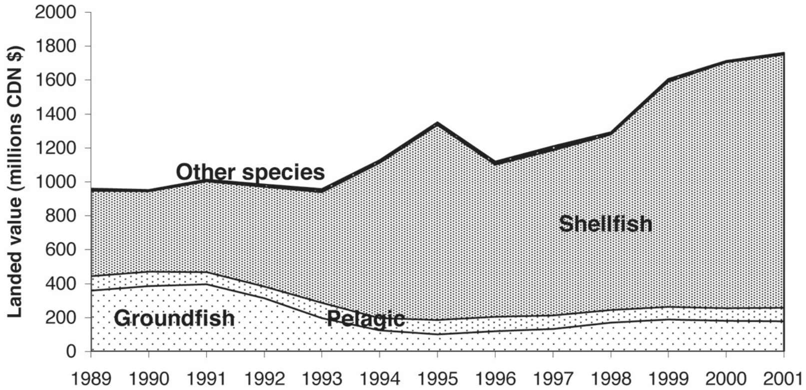

Figure 1. Value of fish products landed in Atlantic Canada (1989–1996). Groundfish and shellfish dominate the value of landings; data include pelagics (second from bottom) and other (top).

affected by the collapse of the groundfish resources and that an ecosystem-based management system that spread the economic benefits among all participants would have suffered no collapse and needed no large-scale public expenditure. Models that included prices, markets, and the social ability to move among different components of the fishery would be needed for application of this system to harvest regulation. In particular, greatly increased attention would have to be given to understanding the "human aspects of the fishery ecosystem."

Pauly (Pauly et al., 2002) and others have argued that ecosystems face collapse because of fishing on nonregulated or by-catch species even when the key commercial species are regulated. They argue that the best way to assure sustainable fisheries is by permanently closing large fractions of the potential habitat to fishing. This view of ecosystem management is not based on a specific ecosystem model, nor does it relate to any specific management objectives, but it is a prescription the proponents believe to be robust to natural fisheries dynamics and the uncertainty in the alternative regulatory systems.

A Case Study Illustrating Alternative Approaches: The West Coast Groundfish Multispecies Fishery.—In this section we describe a specific complex multispecies fishery and explore the application of approaches 2 and 3 (maximizing the sum of single-species benefits; minimizing the chance that any individual stock will be in an overfished state), as examples of approaches to ecosystem management.

The West Coast groundfish fishery (WCGF) consists of four main sectors: commercial limited entry (subdivided into limited-entry trawl and limited-entry fixed gear), open access (fishers without limited-entry permits and those fishing for other species), recreational, and tribal. It operates along the U.S. West Coast from the U.S.-Canada border to the U.S.-Mexico border. The fishery management plan for this fishery includes 83 species of rockfish, roundfish, flatfish, and sharks, although only a handful of these are managed actively. The bulk of the catch (85% by mass; 26% by value of commercial landings in 2000) consists of Pacific whiting, one of the roundfish. Other main target species are sablefish (28% of the value of commercial landings in 2000), dover sole, thornyheads, widow rockfish, arrowtooth flounder, petrale sole, and yellowtail rockfish.

Figure 2 shows time trajectories of population size for 12 of the species in this fishery (Table 1). These 12 species comprised 61% of the total value of the landings by the commercial sector of the fishery in 2000 (83% of the value of the landings of species other

Table 1. Species included in the analyses.

Species	Scientific name	Current status[a]	Assessment	Average price (U.S. \$ kg^{-1})
Rockfish				
Bocaccio	*Sebastes paucispinis*	Overfished	MacCall (2002)	1.55
Canary rockfish	*Sebastes pinniger*	Overfished	Methot and Piner (2002)	1.31
Chilipepper rockfish	*Sebastes goodei*	Above $0.4B_0$	Ralston et al. (1998)	1.34
Longspine thornyhead	*Sebastolobus altivelis*	Above $0.4B_0$	Rogers et al. (1997)	2.22
Pacific Ocean perch	*Sebastes alutus*	Overfished	Ianelli et al. (2000)	0.96
Shortspine thornyhead	*Sebastolobus alascanus*	Precautionary zone	Piner and Methot (2002)	2.22
Widow rockfish	*Sebastes entomelas*	Overfished	Williams et al. (2000)	0.97
Yellowtail rockfish	*Sebastes flavidus*	Above $0.4B_0$	Tagart et al. (2000)	0.99
Other groundfish				
Lingcod	*Ophiodon elongatus*	Overfished	Jagielo et al. (2000)	2.38
Sablefish	*Anoplopoma fimbria*	Precautionary zone	Schirripa and Methot (2002)	3.22
Flatfish				
Dover sole	*Microstomus pacificus*	Precautionary zone	Sampson and Wood (2002)	0.78
Petrale sole	*Eopsetta jordani*	Above $0.4B_0$	Sampson and Lee (1999)	2.24

[a]Overfished, current biomass $< 0.25B_0$; Precautionary zone, $0.25B_0 \leq$ current biomass $< 0.4B_0$.

than Pacific whiting). Four of these species are currently above the B_{MSY} proxy of 40% of the unfished population size (henceforth referred to as $0.4B_0$) and five have been designated overfished at present (depleted to less than 25% of the unfished population size).

Overall, the 12 species are depleted to 30% of the 1935 level, i.e., below the conventional B_{MSY} proxy of $0.4B_0$ but above the overfishing threshold of $0.25B_0$. Management of the WCGF has been based on trip limits by species and area (originally weekly, but now bimonthly), gear restrictions (e.g., prohibitions on the use of small footropes in waters deeper than 100 fa), and, recently, area closures. The management regulations are selected to yield desired levels of fishing mortality (originally $F_{30\%}$, the fishing mortality at which the spawner biomass per recruit is reduced to 30% of its unfished level, but more recently $F_{45\%}$ and $F_{50\%}$ given an improved understanding of the inherent lack of productivity of rockfish populations; see, e.g., Dorn, 2002; Methot and Piner, 2002). It is perhaps noteworthy that the depletion to 30% of the 1935 biomass in Figure 2 is almost exactly that which would be expected had $F_{30\%}$ been applied correctly and recruitment been independent of spawner stock size.

Technological interactions exist among the species caught in the WCGF. The qualitative (and to some extent quantitative) impact of these interactions can be assessed if the annual exploitation rate is modeled as the sum of the exploitation rates imposed by each of the "fisheries" that capture West Coast groundfish, i.e., on the assumption that population dynamics can be mimicked by the discrete deterministic Schaefer production model (Hilborn and Walters, 1992):

$$B_{y+1}^{s} = B_{y}^{s} + r^{s} B_{y}^{s} \left(1 - B_{y}^{s} / K^{s}\right) - \sum_{f} F_{y}^{f} \phi^{s,f} B_{y}^{s} \tag{1}$$

where B_y^s is the biomass of species s at the start of year y, r^s is the intrinsic growth rate for species s, K^s is the carrying capacity for species s (assumed to be invariant with time), F_y^f is a measure of the exploitation rate during year y on fully selected animals by fleet f, and $\phi^{s,f}$ is the relative selectivity of fleet f on species s.

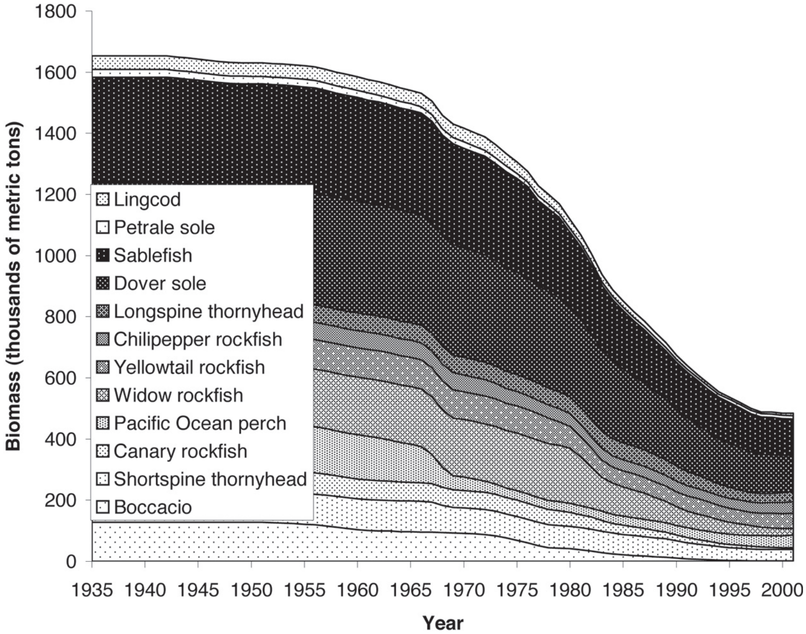

Figure 2. Time-trajectories of biomass (in thousands of metric tons) for 12 West Coast groundfish species.

The results of this section are based on applying the model reflected in Eq. 1 to the 12 species in Table 1 and Figure 2. (Although data are available for Pacific whiting, this species is omitted from the analyses because its fishery is quite different from those for the remaining species included in the Groundfish Fishery Management Plan.) Seven fishing fleets (Table 2) are considered for the analyses of this section. These fleets differ in location (north or south of Cape Mendocino, 40°10′N) and main target species. These fleets are currently used as the basis for determining expected by-catch rates when the Pacific Fishery Management Council determines annual management measures.

The biology represented by Eq. 1 is simple because (a) the dynamics of each target species is assumed to be representable by an age-aggregated model; (b) all fleets have the same selectivity pattern; (c) the impact of stochastic variation in the population-dynamic processes is negligible; and (d) the impacts of trophic interactions are minor. However, these assumptions are unlikely to be severely violated in reality, at least to the extent that the qualitative conclusions of the analysis are concerned. For example, time trajectories of biomass for most West Coast groundfish species are one-way trips that can be captured adequately by Eq. 1; natural mortality is low for most of these species (0.2 yr^{-1} or less), so recruitment variation is largely damped out; the catches are predominantly taken by one gear type (an exception is sablefish, which are harvested extensively by trawl and nontrawl methods); and the results of Ecosim modeling suggest that the impact of trophic interactions on these target species is relatively limited compared that in other multispecies fisheries off the U.S. West Coast (J. Field, School of Aquatic and Fishery Sciences, Univ. Washington, pers. comm.)

The intrinsic growth rate, the carrying capacity, and the biomass at the beginning of 2002 for each species and the values for the relative selectivities must be determined before the population can be projected forward under Eq. 1. The first three were calcu-

Table 2. Fishing fleets included in the analyses.

Region	Main target species
North of 40°10′	Arrowtooth flounder
North of 40°10′	Dover sole, thornyheads, sablefish
North of 40°10′	Flatfish
North of 40°10′	Petrale sole
North of 40°10′	Widow rockfish
South of 40°10′	Dover sole, thornyheads, sablefish
South of 40°10′	Flatfish

lated by projection of each species from 1935 until 2001 with Eq. 1. The last term of Eq. 1 was replaced by the reported catch for year *y*, and the carrying capacity and intrinsic growth were selected to mimic, as closely as possible, estimates of biomass for the first and last years included in the relevant assessment (see Table 1), any estimate of the F_{MSY} exploitation rate, and, for the overfished species, the time needed to recover to $0.4B_0$ in the absence of exploitation. The biomass at the beginning of 1935 was either assumed equal to the carrying capacity (canary rockfish, chilipepper rockfish, lingcod, Pacific Ocean perch, the thornyheads, widow rockfish, and yellowtail rockfish) or assumed to be in equilibrium with respect to the earliest catch.

The relative selectivities were determined from the by-catch rates for 1999 (J. Hastie, NMFS Northwest Fisheries Science Center, pers. comm.):

$$\phi^{s,f} = \frac{C^{s,f}_{1999}}{B^{s}_{1999}} \frac{C^{s}_{1999}}{\sum_f C^{s,f}_{1999}} \tag{2}$$

where $C^{s,f}_y$ is the catch of species *s* by fishery *f* during year *y* and C^{s}_y is total catch (all fishing methods) of species *s* during year *y*.

The second term of Eq. 2 reflects sources of harvest mortality of West Coast groundfish species other than the seven fleets considered here.

The default values for the fleet-specific exploitation rates (assumed to be invariant with time) were determined by maximization of the (undiscounted) total revenue over the next 100 yrs:

$$\sum_s p^s \sum_f F^f \phi^{s,f} B^s_y \tag{3}$$

where p^s is the price per kilogram for species *s* (assumed invariant with time and equal to that for 2000 (see Table 1), in the absence of a model of the relationship between, inter alia, price and volume landed).

Figures 3 and 4 show population biomass (expressed relative to the unfished level) and catch (in 2000 dollars landed value) for each of the 12 species. The projections from 1935–2001 are based on fitting the results from actual assessments (see Table 1), whereas the projections beyond 2001 are based on the default values for the fleet-specific exploitation rates. The horizontal lines in Figure 3 indicate the overfishing threshold (dashed line); the target level of the Pacific Fishery Management Council of $0.4B_0$ (dotted line); and the $0.5B_0$, the biomass at which MSY is achieved for a Schaefer model (solid line).

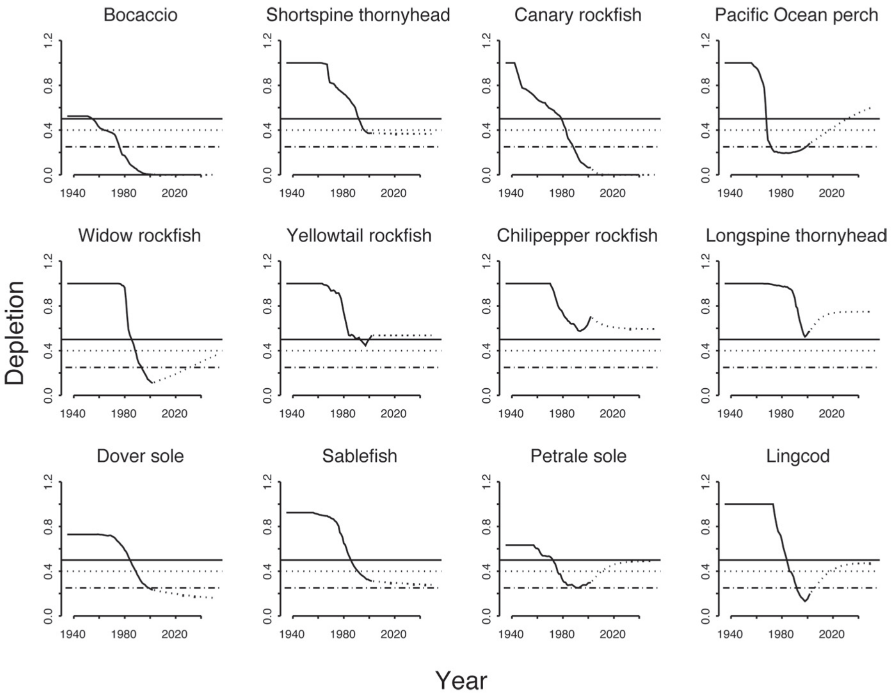

Figure 3. Population biomass expressed as a fraction of the unfished biomass for the 12 species. The projections beyond 2001 (shown as dotted lines) are based on the default fleet-specific exploitation rates. The horizontal lines indicate $0.25B_0$, $0.4B_0$ and $0.5B_0$.

Figure 5 shows results for a range of levels of effort. For simplicity, each level of effort corresponds to multiplying the vector of default fleet-specific exploitation rates by a constant (i.e., the results for 0.5 in Figure 5 are based on fleet-specific exploitation rates that are all half the default values). The results reported in Figure 5 are the average annual catch over the next 100 yrs expressed in 2000 prices, the number of species (out of 12) below the overfished threshold of $0.25B_0$ in 2102, and the number of species below the target level of $0.4B_0$ in 2102. Figure 5 also shows the trade-off between catch and number of overfished/below-target species.

The primary result of this analysis is that, for the ecosystem yield to be maximized (in terms of either biomass or economic value of the catch), some of the species must be overexploited. These calculations suggest that about 90% of the potential yield must be lost to prevent any of the 12 species examined from being overfished. The results in Figures 3–5 overestimate the impact of the current management system; in principle, higher yields could be obtained with lower risk by means of, for example, in-season management, an aspect not considered in the model.

The simple example of Figures 3–5 demonstrates the contradictions of ecosystem management within the present regulatory framework: (1) Some stocks will always be overfished if the objective is to maximize benefits to society, and (2) almost all of the potential yield from the fishery will be forgone if the objective is to prevent overfishing for all stocks. Figures 3–5 are restricted to 12 species because we lack stock assessments for the remaining species; had assessments been available for all 83 species included in the Groundfish Fishery Management Plan, at least one would be classified as overfished each year, because of either natural variation or stock-assessment error. The current system

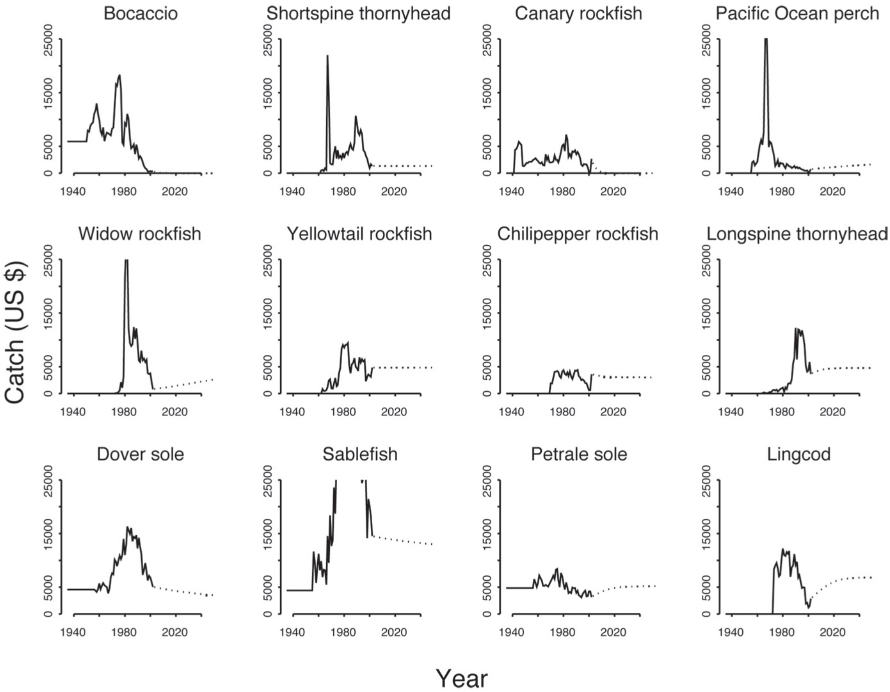

Figure 4. Catches (expressed in 2000 dollars landed value) for the 12 species. The projections beyond 2001 (shown as dotted lines) are based on the default fleet-specific exploitation rates.

of weak-stock management and large-spatial-scale regulations is therefore incompatible with sustainable fisheries.

These results demonstrate that the cost of approach 3 (weak-stock management) is a substantial loss in harvest and benefits to society but that the cost of approach 2 (maximizing single-species benefits) is continued overfishing of some stocks. Note that, given the apparent lack of strong trophic interactions among the target species of the WCGF, the results for approach 1 would be similar to those for approach 2 had the analysis been based on a model of the trophodynamics of the system, even though trophodynamics models include no convenient definition of overfishing. Although the model presented is clearly a simplification of reality, and the parameters are not estimated formally, the qualitative results are nevertheless probably fairly robust. Furthermore, the general conclusions are not terribly surprising; similar results have arisen from stochastic models when mixed-stock management in Pacific salmon was examined (Paulik et al., 1967; Hilborn, 1976) and have been suggested for the WCGF (Hightower, 1990).

The severity of the trade-off between maximizing benefits and minimizing the number of overfished stocks can clearly be reduced if ways could be found to exploit the more productive stocks differentially while protecting those that are less productive. For example, a technological solution would be development of fishing gear that specifically harvested productive stocks and not less productive stocks, but given the large number of species in the WCGF, and the physical similarity of many of them, a technological solution seems unlikely. Marine protected areas are being widely advocated as the solution to the problems associated with this fishery and many similar problems. No formal analysis of marine protected areas has been done, but if the more productive species have

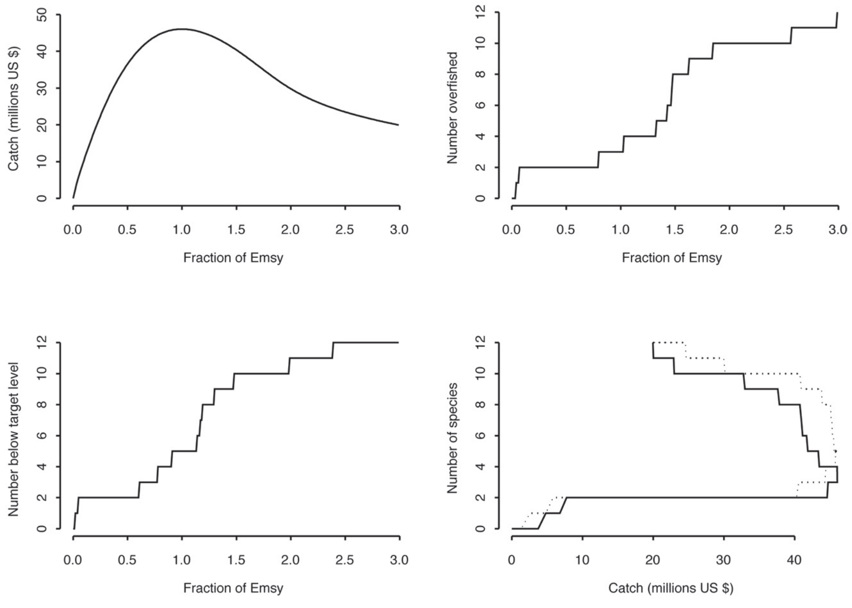

Figure 5. Average annual catch (2002–2101; expressed in 2000 landed value), number of overfished species, and number of species below the $0.4B_0$ target level versus effort, and the trade-off between catch and the number of overfished and below-target species. Emsy is the level of effort that would produce maximum sustainable yield.

spatial distributions different from those of the less productive species, then a network of protected areas might go some way toward preventing overexploitation of the latter. Unfortunately, given the low optimum yields needed for recovery of currently overfished species, the protected areas would have be very large because even small catches will severely reduce recovery times, thereby severely constraining fishing opportunities for more productive species.

In the remainder of this paper, we will discuss how adding the human component to our definition of "ecosystem management" can reduce the conflict between maximization of yield and overexploitation of less productive stocks.

Including Humans in the Ecosystem

The trade-off seen in the WCGF illustrates one element of ecosystem management, but the problem with fisheries management runs much deeper. Overfishing and the consequences of discarding and gear damage to habitats, we argue, are symptoms of poor governance systems rather than the problem per se. In fact, emphasis on overfishing, often associated with lowered catch limits, may be misleading. Overfishing is causing only a 14% loss in yield in the U.S. (NMFS, 1999). This loss (~U.S. $500 million) is relatively small compared to the U.S. $2.9 billion in wasted expenditure in U.S. fisheries due primarily to overcapitalization and the race for fish. Worldwide, this waste is estimated to be U.S. $100 billion (Christy, 1997). Arguably, the loss of 27 million t worldwide as a result of discarding (over 32% of the landings) is an even greater problem.

Examples from around the world of healthy and well-managed fisheries show that the key to success is a system of marine governance that sets rewards that ensure that what is in fishermens', managers', and scientists' interest is also in society's interest. That is, when humans are considered in the ecosystem, solutions can be found. The majority of existing governance structures in the United States and elsewhere encourage fishermen to overexploit and overinvest.

Examples of Failures.—The New England groundfish fishery has seen declining stock abundance since the establishment of the U.S. exclusive economic zone in 1978, and throughout the 1980s and 1990s, the scientific advice has consistently called for reduced catches (National Research Council, 1998). This fishery is plagued by overcapitalization, yet, throughout this period, the commercial fishing industry consistently opposed catch restrictions. This stance would appear to be contrary to their own interests—if they would simply reduce catches now, higher catches in the future would more than compensate. When one recognizes, however, that only a small portion of the possible fishing licenses are active, it is easily shown that, if stocks were rebuilt, the benefits would be shared by a much wider group of license holders, and the currently active fishermen who would make the immediate sacrifice would not receive a big enough share of the future rewards to make it individually worthwhile. The opposition to catch restrictions is therefore perfectly understandable. If the currently active fishermen were guaranteed to receive all of the benefits of rebuilding through some form of marine tenure, the incentives for rebuilding would be much greater.

The fishery for abalone (*Haliotis kamtschatkana*) in British Columbia was closed in 1990 because the stock was seriously depleted. Since then, no significant recovery has occurred, and illegal fishing is widely recognized as keeping the stock in an overexploited condition. Illegal harvesting (often in excess of the legal harvests) is a common feature worldwide of fisheries for high-value products like abalone and lobster, (Anonymous, 1997). National and regional authorities often do not have the resources to enforce regulations, and local communities and individuals have no incentives to police the fishing grounds themselves. Therefore, although the incentives for illegal harvesting are strong, those for its prevention are weak or absent; some fishers may even be both legal and illegal harvesters. If communities or individuals had harvesting tenure on specific abalone beds, they would attempt to protect these beds from illegal fishing and find mechanisms for long-term sustainable harvesting (Prince et al., 1998).

Examples of Successes.—New Zealand instituted a program of individual transferable quotas (ITQs) in its rock lobster (*Jasus edwardsii*) fisheries in 1991. The rock lobster fishery in the Gisborne area in eastern New Zealand was one of the most problematic at the time, because of low catch rates, substantial illegal harvesting, and the inability of commercial fishermen even to catch their allowed quotas (Breen and Kendrick, 1997). A coalition of commercial and recreational fishermen, together with government officials, developed a management plan for this fishery that was intended to reduce illegal fishing and rebuild abundance. The key components were a 50% reduction of the commercial catch limit, reductions in the allowed recreational harvest, and shift of the fishing season to the winter. This program of stock rebuilding was dramatically successful: abundance of legal-sized rock lobster increased fivefold over 5 yrs, the value of the individual ITQ holdings increased sixfold, and by 1999 the total commercial quota had recovered to what it had been prior to the rebuilding plan. The movement of the legal fishery to the winter is felt to have largely eliminated illegal harvest. The system of governance in this fishery established a framework in which rewards for individual behavior were consistent with societally desirable outcomes.

In the Chilean shellfish fishery, more than 40 species are harvested almost exclusively by commercial divers. When this significant industry (25,000 fishers; aggregate catch on the order of 150,000 mt, worth about U.S. $170 million per year; Castilla et al., 1998) was open-access, the most valuable component (loco; *Concholepas concholepas*) was overfished, and the fishery was closed for 3 yrs (1989–1992), much like the British Columbia abalone fishery. The economic consequences and social distortions created by that draconian measure motivated the search for management alternatives (Orensanz et al., 2001, submitted).

As a result, territorial fishing rights were incorporated into the Fisheries Act of 1991. These rights can be requested by village- ("caleta-") based fishers' organizations ("syndicates") and are granted upon presentation of a base-line study and a management plan. The caletas became true partners in de-facto comanagement arrangements (Minn and Castilla, 1995; González, 1996; Castilla, 1997; Stotz, 1997, Bernal et al., 1999).

The contrast is stark between the status of the stocks within the territories owned by caletas and those in open-access "historical grounds": fishermen are highly protective of the first, whereas a "tragedy of the commons" situation prevails in the latter. As a result, caletas that have requested and managed territories have been comparatively successful. Full, wide-scale implementation of the system effectively began by 1998 (Orensanz et al., submitted). The territorial fishing rights system has also had other positive effects: gathering of knowledge about the response of the stocks to the harvest, quality of the product and reliability of supplies, and—most important—strengthening of caletas stemming from shared responsibilities and appropriate incentives.

The fishery for sablefish (*Anoplopoma fimbria*) off British Columbia has been managed since 1990 under a program of ITQs (Turris, 2000). The nature of the governance system, in which the asset value is high and strongly affected by the perceived sustainability of the resource, has changed the incentive structure of the fishery participants. For example, the Canadian Sablefish Association, an organization in which all the quota holders participate voluntarily, funds independent scientists to assess the sablefish resource annually, in addition to conducting a biological sampling program, a tagging program, and other research activities. The association has also developed an escape-ring technology that permits young sablefish to escape the traps undamaged and is working on a technology that will prevent large females from entering the traps. This association is therefore a model for responsible behavior by commercial fishing groups. It is currently negotiating with the Canadian government to assume more of the responsibility for data collection, stock assessment, and management.

Setting Appropriate Incentives.—All of the examples above illustrate that individuals and groups acting to maximize their own welfare can also produce societally desirable outcomes. The hypothesis we propose is that sustainable fishing will occur when the institutional framework encourages the participants to behave in a way that is considered optimal for society.

Although the scientific community (dominated by biologists) has concentrated primarily on the problem of overfishing, and its view of ecosystems largely excludes humans, economists have identified excess fishing capacity as the primary problem with fisheries at least since the 1950s (e.g., Gordon, 1954; Pearse, 1992). Many of the current regulatory systems, such as limited entry, ITQs, and auctioning of fishing rights, are derived from the analysis and advice of economists, whose definition of ecosystem management includes fishing fleets.

The governance system must set appropriate incentives for all parties involved in the fishery. Although the motives of fishermen are undoubtedly complex, we suggest that reward structures that maximize fishermen's income within the constraints of biological sustainability will work well. Marine tenure is a clear first step. Whether they resemble the territorial rights of the Chilean caletas or the ITQ systems of the New Zealand lobster and Canadian sablefish fisheries, these systems eliminate the incentives for overcapacity associated with the race for fish and encourage both conservation and prevention of illegal fishing. These forms of marine tenure do not necessarily provide incentives for prevention of by-catch, so additional incentives may also be needed, such as by-catch quotas.

Not all forms of marine tenure must be community- or individual-based. The geoduck (a large valuable clam) fishery in Puget Sound is managed by the Washington State Department of Natural Resources, which auctions the right to harvest specific quantities of geoduck on specific beds at specific times. These auctions bring in approximately U.S. $7 million to the state of Washington, of which approximately U.S. $2 million is used for research, management, and enforcement (L. Espy, Washington Department of Natural Resources, Olympia, Washington, pers. comm.). Washington State has true marine tenure in this case, and, unlike the situation in almost all of the world's commercial fisheries that are state owned, the management agency responsible has received most of its funding directly from resource users.

Fisheries management can be done either "top down," by means of regulations, enforcement, and lawsuits, or "bottom up," by means of incentives set so that participants in the fishery acting in self interest will promote conservation. Bottom-up management is the carrot, top-down management is the stick. Top-down management can achieve narrow goals in societies that have appropriate institutions. The International Pacific Halibut Commission was able to achieve good biological management by intensive regulation, producing a fishing season that often lasted for only 24 hrs and was characterized by incredible overcapitalization, economic waste, loss of life, and illegal fishing (Hilborn, in press). When an ITQ system was established for halibut, the asset value to individual fishermen often exceeded $1 million, and promoting conservation and economic efficiency was clearly in their interest. Although many societies can use the top-down approach and achieve satisfactory biological results, this approach fails to address the economic issues, which are only solved through appropriate incentives.

Many countries do not have the infrastructure to enforce regulations, and in those situations, the top-down approach simply is not possible. The above-described system established in Chile illustrates this point well, as does a series of case studies in which reestablishment of traditional village-based marine tenure in Pacific island countries allowed local communities to rebuild their fishery resources (Johannes, 1978, 1998, 2002).

The dynamics of management institutions has received growing attention in recent years, largely led by social scientists (Ostrom, 1990; Heinz Center, 2000). Incentives are needed that can solve the economic, by-catch, and sustainable-yield problems of the world's fisheries. Whichever interpretation of ecosystem management we choose, it is only one tool in the attempt to solve one of the problems, and although we should move ahead in applying ecosystem understanding to our current regulatory structure, we must recognize that much more fundamental changes are needed. Breaking the race for fish by adopting societally appropriate marine tenure systems should be an immediate priority.

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Literature Cited

Anonymous. 1997. Review of the state of the world's fisheries resources: marine fisheries. FAO Fisheries Circular No. 920. Food and Agriculture Organization of the United Nations, Rome.

Bernal, P. A., D. Oliva, B. Aliaga, and C. Morales. 1999. New regulations in Chilean fisheries and aquaculture: ITQ's and Territorial Use Rights. Ocean Coastal Manage. 42: 119–142.

Botsford, L. W., J. C. Castilla, and C. H. Peterson. 1997. The management of fisheries and marine ecosystems. Science 277: 509–515.

Breen, P. A. and T. H. Kendrick. 1997. Evaluation of a management decision rule for a New Zealand rock lobster substock. Mar. Freshw. Res. 48: 1103–1110.

Butterworth, D. S. and A. E. Punt. 2003. The role of harvest control laws, risk and uncertainty and the precautionary approach in ecosystem-based management. Pages 311–319 *in* M. Sinclair and G. Valdimarsson, eds. Responsible fisheries in the marine ecosystem. FAO and CABI Publishing, Rome and New York.

Castilla, J. C. 1997. The sustainable use of marine coastal resources in Chile: co-management and the artisanal fishing communities. Pages 138–147 *in* Science for sustainable development in Latin America and the Caribbean. Proceedings of the Third World Academy of Sciences 6th General Conference, Rio de Janeiro, Brazil, September 1997.

__________, P. Manríquez, J. Alvarado, A. Rosson, C. Pino, C. Espoz, R. Soto, D. Oliva, and O. Defeo. 1998. Artisanal "caletas" as units of production and co-managers of benthic invertebrates in Chile. Pages 407–413 *in* G. S. Jamieson and A. Campbell, eds. Proceedings of the North Pacific symposium on invertebrate stock assessment and management, Can. Spec. Publ. Fish. Aquat. Sci. 125. National Research Council of Canada, Ottawa.

Christy, F. T. 1997. Economic waste in fisheries: impediments to change and conditions for improvement. Pages 28–39 *in* E. K. Pikitch, D. D. Huppert, and M. P. Sissenwine, eds. Global trends: fisheries management. Amer. Fish. Soc. Symp. 20. American Fisheries Society, Bethesda, Maryland.

Costanza, R., F. Andrade, P. Antunes, M. van den Belt, D. Boersma, D. F. Boesch, F. Catarino, S. Hanna, K. Limburg, B. Low, M. Molitor, J. G. Pereira, S. Rayner, R. Santos, J. Wilson, and M. Young. 1998. Principles for sustainable governance of the oceans. Science 281: 198–199.

Dorn, M. W. 2002. Advice on west coast rockfish harvest rates from Bayesian meta-analysis of stock-recruit relationships. N. Amer. J. Fish. Manage. 22: 280–300.

González, E. 1996. Territorial use rights in Chilean fisheries. Mar. Resourc. Econ. 11: 211–218.

Gordon, H. S. 1954. Economic theory of a common property resources: the fishery. J. Political Econ. 62: 124–142.

Heinz Center (H. John Heinz III Center for Science, Economics, and the Environment). 2000. Fishing grounds: defining a new era for American fisheries management. Island Press, Washington, D.C. 241 p.

Hightower, J. E. 1990. Multispecies harvesting policies for Washington-Oregon-California rockfish trawl fisheries. Fish. Bull., U.S. 88: 645–656.

Hilborn, R. 1976. Optimal exploitation of multiple stocks by a common fishery. J. Fish. Res. Bd. Can. 33:1–5.

_________ (in press). Are sustainable fisheries achievable? *In* E. A. Norse and L. B. Crowder, eds. Marine conservation biology: the science of maintaining the sea's biodiversity. Island Press, Washington, D.C.

_________, J. J. Maguire, A. M. Parma, and A. A. Rosenberg. 2001. The precautionary approach and risk management: can they increase the probability of success in fisheries management? Can. J. Fish. Aquat. Sci. 58: 99–107.

_________ and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York. 570 p.

Ianelli, J. N., M. Wilkins, and S. Harley. 2000. Status and future prospects for the Pacific Ocean perch resource in waters off Washington and Oregon as assessed in 2000. Appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. 54 p.

Jagielo, T., D. Wilson-Vandenberg, J. Sneva, S. Rosenfield, and F. Wallace. 2000. Assessment of lingcod (*Ophiodon elongates*) for the Pacific Fishery Management Council in 2000. Appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. xii+142 p.

Johannes, R. E. 1978. Traditional marine conservation methods in Oceania and their demise. Ann. Rev. Ecol. Syst. 9: 349–364.

_____________. 1998. Government-supported, village-based management of marine resources in Vanuatu. Ocean Coastal Manage. 40: 165–186.

_____________. 2002. The renaissance of community based resource management in Oceania. Ann. Rev. Ecol Syst. 33: 317–340.

MacCall, A. D. 2002. Status of bocaccio off California in 2002. Unpublished report to the Pacific Fishery Management Council, Portland, Oregon. 41 p.

Magnusson, K. G. 1995. An overview of the multispecies VPA—theory and applications. Rev. Fish Biol. Fish. 5: 195–212.

Methot, R. and K. Piner. 2002. Status of canary rockfish off California, Oregon and Washington in 2001. Unpublished report to the Pacific Fishery Management Council, Portland. 134 p.

Minn, I. and J. C. Castilla. 1995. Small-scale artisanal fishing and benthic invertebrate management in Caleta Las Cruces, Central Chile. Out of the Shell 5: 11.

NMFS (National Marine Fisheries Service). 1999. Our living oceans: report on the status of U.S. living marine resources, 1999. U.S. Dept. Commerce, NOAA Tech. Memo NMFS-F/SPO-41. 301 p.

National Research Council. 1998. Review of the northeast fishery stock assessments. Natl. Academy Press, Washington, D.C. 128 p.

_________. 1999. Sustaining marine fisheries. Natl. Academy Press, Washington, D.C. 164 p.

Orensanz, J. M., R. Hilborn, and A. M. Parma. 2001. Harvesting Methuselah's clam—is the geoduck fishery sustainable, or just apparently so? Canadian Stock Assessment Secretariat (CSAS), Research Document 2000/175. 69 p.

_____________, A. M. Parma, G. Jerez, N. Barahona, M. Montecinos, and I. Elias. What are the key elements for the sustainability of "S-fisheries"? Insights from South America. Submitted to N. Erhardt, ed. Proceedings of the conference on the scientific bases for the sustainability of fisheries (Miami, November 26–30, 2001).

Ostrom, E. 1990. Governing the commons : the evolution of institutions for collective action. Cambridge Univ. Press, New York. 280 p.

Paulik, G. J., A. S. Hourston, and P. A. Larkin. 1967. Exploitation of multiple stocks by a common fishery. J. Fish. Res. Bd. Can. 24:2527–2537.

Pauly, D., V. Christensen, S. Guénette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. 2002. Towards sustainability in world fisheries. Nature 418: 689–695.

Pearse, P. H. 1992. From open access to private property: recent innovations in fishing rights as instruments of fisheries policy. Ocean Dev. Intl. Law 23(1): 71–83.

Piner, K. and R. Methot. 2002. Stock status of shortspine thornyhead off the Pacific West Coast of the United States 2001. Unpublished report to the Pacific Fishery Management Council, Portland, Oregon. 161 p.

Prince, J., C. J. Walters, R. Ruiz-Avila, and P. Sluczanowski. 1998. Territorial user's rights and the Australian abalone (*Haliotis* sp.) fishery. Pages 367–375 *in* G. S. Jamieson and A. Campbell, eds. Proceedings of the North Pacific symposium on invertebrate stock-assessment and management. Can. Spec. Publ. Fish. Aquat. Sci. 125. National Research Council of Canada, Ottawa.

Ralston, S., D. E. Pearson, and J. A. Reynolds. 1998. Status of the chilipepper rockfish stock in 1998. Appendix to Status of the Pacific coast groundfish fishery through 1998 and recommended acceptable biological catches for 1999. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. 99 p.

Rogers, J. B., L. D. Jacobson, R. Lauth, J. N. Ianelli, and M. Wilkins. 1997. Status of the thornyhead (*Sebastolobus* spp.) resource in 1997. Appendix to Status of the Pacific coast groundfish fishery through 1997 and recommended acceptable biological catches for 1998. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. 122 p.

Sampson, D. B. and Y. W. Lee. 1999. An assessment of the stocks of petrale sole off Washington, Oregon and northern California in 1998. Appendix to Status of the Pacific coast groundfish fishery through 1999 and recommended acceptable biological catches for 2000. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. 76 p.

_____________ and C. Wood. 2002. Stock status of dover sole off the U.S. West Coast in 2000. Unpublished report to the Pacific Fishery Management Council, Portland, Oregon. 109 p.

Schirripa, M. J. and R. Methot. 2002. Status of the sablefish resource off the continental U.S. Pacific coast in 2001. Unpublished report to the Pacific Fishery Management Council, Portland, Oregon. 95 p.

Schweder, T., G. S. Hagen, and E. Hatlebakk. 1998. On the effect on cod and herring fisheries of retuning the revised management procedure for minke whaling in the Greater Barents Sea. Fish. Res. (Amst.) 37: 77–95.

Stokes, T. K. 1992. An overview of the North Sea multispecies modeling work in ICES. S. Afr. J. Mar. Sci./S.-Afr. Tydskr. Seewet. 12: 1051–1060.

Stotz, W. 1997. Las áreas de manejo en la Ley de Pesca y Acuicultura: primeras experiencias y evaluación de la utilidad de esta herramienta para el recurso loco. Estud. Oceanol. (Chile) 16: 67–86.

Tagart, J. V., F. R. Wallace, and J. N. Ianelli. 2000. Status of the yellowtail rockfish resource in 2000. Appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. xi+127 p.

Turris, B. R. 2000. A comparison of British Columbia's ITQ fisheries for groundfish trawl and sablefish: similar results from programmes with differing objectives, designs and processes. Pages 254–261 *in* R. Shotton, ed. Use of property rights in fisheries management: proceedings of the FishRights99 Conference, Fremantle, Western Australia, 11–19 November 1999. FAO Fisheries Technical Paper No. 404, Vol. 1. Food and Agriculture Organization of the United Nations, Rome.

Walters, C. J., V. Christensen, and D. Pauly. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Rev. Fish Biol. Fish. 7: 139–172.

___________, D. Pauly, V. Christensen, and J. F. Kitchell. 2000. Representing density dependent consequences of life history strategies in aquatic ecosystems: EcoSim II. Ecosystems 3: 70–83.

Williams, E. H., A .D. MacCall, S. V. Ralston, and D. E. Pearson. 2000. Status of the widow rockfish resource in Y2K. Appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon. 122 p.

ADDRESSES: (R.H., A.E.P.) *School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, Washington 98195-5020. E-mail: <rayh@u.washington.edu>.* (J.O.) *Centro Nacional Patagónico, CONICET, Boulevard Brown S/N, 9120 Puerto Madryn, Chubut, Argentina.*