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System vs. Species Management: Big or Little Boxes?

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Introduction

Fisheries economics recognizes the need for property rights, and seeks to create a sole owner, which through exclusion, will either bear all of the costs or enjoy all of the benefits of the future condition of the resource. Loosely defined, the sole owner can take the form of a collective body such as the government, a corporation, a co-op, or a community. However, for social, political, and biological reasons, creating a sole owner in the real world has proven difficult, if not impossible. For the sole owner to function, appropriate feedback must occur to enable the decision-maker(s) to act appropriately. That is, the rights holder(s) must make decisions with some understanding of the impact that a particular action is likely to have. With the numerous levels of uncertainty and predictability that exist in fisheries, both political and biological, it is nearly impossible to know what the future of the resource will be. Depending on the kinds of rights users possess and the scale at which those rights are allocated, appropriate incentives can develop (Wilson and Anderson, 1999). The failure of current fishery management systems to create stewardship and accountability may be due to the lack of feedback that is necessary for decisions makers (sole owners) to manage the resource. This is likely a consequence of the scale of the ecological system at which rights are allocated, which also

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defines, the scale at which management rules are focused. Thus, the scale at which rights are allocated deserves further exploration.

This paper argues that sufficient predictability necessary for decision makers to act appropriately may not be present at the single species level, but may possibly exist at the system, or multiple species, level. If this is correct, the current perspective guiding fisheries management, which relies on single species models, must be revised in order to deal with the complex nature of marine systems. Two multispecies models, each with two ecosystems, are used to explore two different approaches to managing fisheries. One approach allocates harvesting rights to species across ecosystems (the traditional single species approach, or the "Little Box" approach). The second approach allocates rights to multiple species within an ecosystem (an ecosystem approach to management, or the "Big Box" approach.[2] In particular, the models are used to explore whether, and under what conditions, appropriate feedback can be generated depending upon which management approach is accepted.

The Traditional Management Perspective[3]

Relying mainly on single species models, the traditional approach to management assigns rights to individual species and manages those species independently. Probably the most influential single species models are those based upon the S or logistic description of population changes. This model depicts a relationship between the growth of a fish stock and its weight.

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[2] Wilson, Brennan, Acheson. DMR Governance Document.

[3] Described by Acheson and Wilson (1996).

The model finds that recruitment to the population is governed by the size of the population, and that growth (recruitment) will occur until the population reaches its maximum size. After this size, growth of the population declines. This model assumes that there is a population size for each species that the species will tend towards in the absence of fishing. That is, it assumes that there is an attainable equilibrium. Based on this model, effort-yield curves are used to describe the amount fish that can be taken that still allows the stock to sustain its population level. The amount that can be taken that will achieve sustainability is the population's maximum sustainable yield (MSY). Thus, the traditional approach to management is primarily concerned with controlling the number of fish harvested in order to prevent overfishing - defined as the reduction in the spawning capability (reproductive potential) of the stock to the point where the population can no longer sustain itself. Again, the reproductive potential of the population is assumed to be a function of the size of the population.

This perspective assumes that if a resource has been severely depleted and harvesting pressures are removed, then the resource will rebound to its condition prior to harvesting and eventually towards an equilibrium condition. Although examples do exist where fish populations have recovered after the cessation of fishing (e.g. the recovery of fish stocks during world wars), there have also been instances where the result was not as the single species models would have predicted. For example, when spawning area closures were implemented to protect the groundfish resource on Georges Bank in 1994, the expectation was that the groundfish stocks would recover with the removal of fishing pressures. However, 5 years after these areas were closed to fishing, the result was not the recovery of the groundfish populations, but a booming scallop population (citation). Another notable example is then Canadian northern cod fishery which, after 8 years of closure, continues to remain in its depleted condition (Finlayson and McCay, 1998).

Because rights are allocated to individual species across systems and subsystems and rules typically cover the entire range of a particular stock, local conditions and processes (e.g. habitat, local stock structure, fish behavior) are essentially ignored. The traditional approach also fails to recognize the dynamic nature of the system, particularly its temporal and spatial variability. In doing so, it assumes a level of predictability that simply does not exist.

An Alternative Perspective

Even in the absence of fishing pressures, marine ecosystems are highly variable, non-linear systems characterized by complexity (Ludwig et al., 1993?). The system can be viewed as being composed of patchily distributed subsystems, and as having both spatial and temporal heterogeneity. However, despite its non-equilibrium nature, the system as a whole is generally stable. The various components of the subsystems (e.g. species) fluctuate unpredictably, but within a general range. Multiple subsystems create redundancy, which provides resilience for the entire system and for the species that occupy the system (Simon, 1962). Additionally, interactions among the components (species) of the system provide stability. Sissenwine (1984) referred to these interactions as community predation - or the tendency of big fish to eat little fish. These interactions result in what is referred to as compensation between the components.

When one species is reduced or removed, another may be able to take its place. This is due to differences in species that allow them to differentially take up available space in the system. For example, some species in the system are fast growing and short lived, while others are slow growing and long lived.

Compensation may explain the recent growth in the abundance of elasmobranchs (e.g. dogfish and skates) on Georges Bank that has occurred since the depletion of the groundfish populations. Diet overlap could explain why the elasmobranchs were able to increase after the decline in the groundfish populations (i.e. release from competition). Herring and mackerel are important prey for both groundfish and elasmobranch populations. The initial increase in elasmobranchs may be due to the increase in herring, which is believed partly due to the loss of the dominant predators, such as cod. The depletion of the groundfish resource removed an important constraint on these pelagic populations (Fogarty and Murawski, 1998). Another example is when sand lance populations increased dramatically with the decline in herring and mackerel populations in the 1960s (Fogarty and Murawski, 1999). Populations of herring and mackerel were able to recover to historical levels, perhaps since these species feed on postlarval and juvenile sand lance.

With our imperfect knowledge of the interactions in the system and of the impact of humans on future resource conditions, we unfortunately have very little quantitative predictive capability. Not only can we not predict how individual species will behave, we cannot predict how they will react to human intervention. At best we can only predict ahead a few years, based on inertial characteristics of the system, and then our ability to predict quickly breaks down. If, for example, one component of the system is reduced or removed, we do not know, with quantitative confidence, what will result. However, we may have a qualitative understanding of what might happen. There is no way to gain quantitative, long-term predictability without knowing the causal relationships in the system: And, given the non-linear nature of the system, even if we did understand the causal relationships, quantitative predictive capability would still be nearly impossible. The need for decision making under this kind of uncertainty must be accepted and incorporated into management.

An Example of the Failure of the Traditional Perspective: The Gulf of Maine

There have always been primarily two strategies utilized by fishermen in the Gulf of Maine. One strategy is when vessel targets a single species across multiple ecosystems. A notable example of this strategy is the redfish fishery that existed in the 1920s. This fishery traveled from the Gulf of Maine to as far as Labrador targeting only redfish. With the second strategy, fishermen target multiple species in a relatively smaller geographic area. An example of this is the Maine inshore multispecies fishing operation. For example, vessels typically would target lobster in the spring and early summer, groundfish in the summer, shrimp and scallop in the winter. These two strategies give rise to two licensing options for managers. One approach is to allocate harvesting rights to a single species throughout its range. Users refer to this as the *Little Box* approach. The second option is to allocate rights to multiple species within a defined management area. Users refer to this as the *Big Box* approach.

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In the Gulf of Maine region, fisheries have been managed with the traditional, single species management approach, since 1977.[4] Large management areas were established for each species, usually comprising Georges Bank and/or the Gulf of Maine. Prior to this time, fishermen traditionally were able to switch easily between fisheries, allowing them to take advantage of market trends and changes in species abundance. Small fishing operations have long characterized some parts of New England's fishing industry.[5] Inshore, small boat fishermen everywhere are known for switching from fishery to fishery (or from species to species) as needed, and the small boats in New England are no exception (Acheson, 1978). These small boats are generally not able to move across multiple ecosystems to chase individual species. Only large vessels are capable of this migration. Therefore, small boat fishermen generally prefer switching from fishery to fishery (or species to species).

By establishing licenses for individual fisheries, creating what users refer to as "Little boxes", the flexibility that had long sustained New England's small boat fleet quickly disappeared.[6] Fishermen were forced to chase the species for which they were licensed across multiple ecosystems (i.e. Georges Bank and the Gulf of Maine), requiring larger vessels. Traditionally, fishermen were able to follow the natural variability of the system, which

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[4] Among the important commercial species in this region are groundfish (e.g. cod, haddock, flounders), scallops, shrimp, lobster, and herring.

[5] Except the large, single species boats of the 19th century that fished on the Grand Banks and beyond.

[6] Limited entry management was implemented, and access to fisheries was generally established through a licensing system based on historical participation in the fishery. In most cases, individual licenses are required to harvest different species. One notable exception is the limited access permits in the New England Mulitspecies groundfish

permitted depressed stocks to recover when depleted. When only given limited options as to what species they can target, fishermen are forced to continue to deplete stocks that are in decline.

The result of the single species management approach in the Gulf of Maine has been the depletion of nearly all of the harvestable fish stocks in this region. Prior to 1994, most of the large vessels fished offshore on Georges Bank, where many of the small vessels could not travel. However, in 1994, large parts of Georges Bank were closed to groundfishing due to the severely depleted condition of the resource. The large vessels were then forced into the Gulf of Maine, which can be considered a separate ecosystem from Georges Bank. This additional effort was simply too much for the resource to sustain, and the Gulf of Maine fish stocks were quickly depleted. Many of the smaller fishing operations were displaced as a result of the large boats. Eventually, the fish stocks on Georges Bank began to recover and the large boats returned, leaving a depleted GOM for the small boats. Had there been legislation in place to prevent the relocation of fishing effort from Georges Bank to the Gulf of Maine, not only would many of the small boat fishermen still be in business, but the resource may not have been so quickly depleted. Furthermore, allocating rights in this way leaves no incentive for the development of stewardship or accountability in the Gulf of Maine. Small vessels have no assurance that they, and not the large boats, will benefit from any conservation efforts that they make.

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fishery, which now includes 13 species. However, some rules that regulate this fishery are species specific (e.g. Total Allowable Catches), and thus, the single species management approach prevails.

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Evidence suggests that had local ecosystem processes and structures (e.g. spawning, habitat, stock structure) been protected, the inshore cod and haddock stocks that were once abundant in the inshore waters of the Gulf of Maine would not have disappeared (Ames, 1996). These local conditions are ignored with the large-scale approach to management. Wilson et al. (1999) found that local conditions are important, and if misperceived can result in a different kind of overfishing than simply the removal of too many fish. Only management at a local scale can address these local conditions.

In considering these findings and the failure of the traditional management approach, many argue that an alternative to the traditional large scale, single species approach is necessary (Wilson, 2000). Recently, interest for community-based, or co-management, approaches to fisheries management has been developing rapidly. This approach finds that by giving users decision making authority and responsibility, stewardship incentives and accountability can develop and sustainable use of the resource is possible (e.g. Pomeroy, 1998). The co-management approach is also better suited for addressing local issues. The literature is richly filled with examples of successful community based management systems (e.g. Pinkerton and Weinstein, 1995; Ostrom, 1990; Dyer and McGoodwin, 1994). In fact, co-management has been implemented in several local fisheries in the Gulf of Maine. The most notable and successful example is Maine's lobster zone management council process (Acheson, 1999).

Co-management seems to work best when areas are well defined (i.e. when boundaries exist). Co-management also works well when individuals are able to monitor the activities of other users. Therefore, self-enforcement (and government enforcement) of rules is easier in a small geographic area. Although rarely considered for large scale, mobile, multispecies fisheries, co-management does offer a possible alternative to the traditional approach for New England multispecies groundfish fishery.

This paper hypothesizes that instead of geographic flexibility, fishermen should be given the flexibility to switch from species to species (e.g. fishery to fishery), within defined local management areas (e.g. ecosystems).[7] If marine systems are accepted as being highly variable and complex, allocating rights to comparatively smaller geographic areas (local scales) and allowing users to fish multiple fisheries makes more sense (citation). This would give users "Big boxes" to work in, and would allow for the protection and maintenance of local processes and structures that provide the system with resilience and stability, and can provide incentives for conservation.

*A **Multiple Species Fisheries Model***

In order to explore the dynamics of a multispecies fishery and the implications of the two management approaches previously described, two age-structured, multiple species models were created using the graphical programming language STELLA 5.0.[8] Both models are complex and function similarly to ones used by Wilson et al. (1991) and Wilson et al. (1999). One model simulates the traditional single species approach to management (or the Little Box model), and

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[7] Boundaries of the management area should, if possible, encompass the boundaries of the ecosystem. However, this is made problematic by the fluid nature of the environment.

the other replicates the ecosystem approach (or the Big Box model). Each model consists of two biological sectors, representing two geographically proximate ecosystems, and an economic sector that governs harvesting activities.[9] Both models view the system as complex and dynamic, and so the two ecosystems are considered to be a part of a complex system composed of nearly decomposable subsystems (or discrete areas). The two ecosystems are, therefore, considered local but may be connected by larval drift or migration.[10]

In developing these models, three characteristics believed to typify multiple species systems were intentionally included. These characteristics described by Wilson et. al. (1991) are (1) relative dynamic stability of the overall biomass of the system with highly variable, unpredictable component populations, (2) energy efficiency (e.g. due to resource limitations), and (3) compensation due to negative feedback through community predation at the larval and post-larval stage of the species life history (prior to recruitment) (Wilson et al. 1991). These characteristics were achieved as a result of the differentiation of the species and a system biomass constraint. The system biomass constraint is included to represent the system's carrying capacity. For the purposes of this paper, ecosystems in each model are given identical carrying capacities.

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[8] The models were created through a joint effort between Dr. J.A.Wilson, D.F. Gilbert, and the author.
[9] The biological sector was adapted from the FORTRAN Model used by Wilson et. al 1991.

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The Biological Sectors (or the Ecosystems)

Each biological sector is similar and contains five age-structured populations. These populations have been labeled, for convenience only, Herring, Cod, Haddock, Redfish, and Sand Lance. The species were loosely modeled after several species found in the Gulf of Maine region. However, it was necessary to slightly alter some aspects of the species life history characteristics in order to differentiate them. Differentiation of the species was necessary to represent the diversity of species that exists in real world ecosystems.

Herring is a light, fast growing, short-lived (seven age classes), and relatively fecund species. Herring reaches sexual maturity at age three, a year after it is recruited to the fishery. Additionally, this species experiences the highest natural mortality. Cod grows fast and large, and is very fecund. It has an intermediate life span of 10 years. Haddock is longer-lived (14 years) and less fecund than cod. Both species are susceptible to harvesting at age 3, a year before they reach sexual maturity. Redfish is a long lived (11 year classes), slow growing species, that experiences relatively low natural mortality. This species reaches maturity later (age 7), and is assumed to invest more energy into ensuring the survival of its young. Therefore, it produces comparatively fewer eggs that are less susceptible to larval (pre-recruitment) mortality. In addition, redfish is not harvested until age 5. Sand Lance represents a "bloom" species that is capable of taking advantage of unused energy (e.g. food) in the system. This species is not harvested, and represents the untouched biomass that is present in most marine

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[10] No larval drift or migration was included for the purposes of this paper.

ecosystems. It is a lighter species than herring, but has the same number of age classes and reaches maturity at the same age. Because it is unharvested and is the most fecund of all the species in the system, sand lance can dominate the system when everything else is heavily fished. This allows overfishing with relative biomass stability.

Changes in the population size of each species are determined by density-dependent egg survival rates, natural mortality, and fishing induced mortality. A density-dependent mortality rate controls the number of eggs that survive to age 1, and is a function of the total size of the species population. Due to the high levels of interactions between these species, the populations are very sensitive to changes in the number of births and natural mortality rates. Additionally, the species in the system are also constrained by a system carrying capacity. The carrying capacity represents the total biomass that the system can maintain. As the total biomass of the system (or the sum biomass of each species) nears the carrying capacity, the individual species experience additional mortality on age 0 and age 1 classes. Survival of age 1 fish are also influenced by an additional density-independent mortality that represents variability needed to differentiate the species and allow for compensation. This mortality is randomly generated.

The Economic Sectors

The economic sector of the first model differs substantially from that of the second model. In the first model, the Little Box model, fishing rights are allocated on a single species basis, and so fishing occurs across the two ecosystems and each boat is restricted to fishing a single species. In the second model, fishing rights are allocated within one ecosystem and vessels are allowed to switch between species. Decisions in both models are based on the relative profitability of the options available.

Two ownership regimes are modeled; Open Access and Sole Owner management. With *Open Access,* entry occurs when average profits are positive and exit occurs when average profits are negative. When no profits occur, no entry or exist occurs. The model assumes that harvesters do not have problems finding alternative forms of employment, and that no regulatory barriers exist to impede entry. There are also no lags in entry and exit. Additionally, in the Little Box model, current profits per boat are compared between regions, and a proportion of the vessels will migrate towards the most profitable region. In the Big Box model, individual vessels compare the relative profitability between fishing for the currently targeted species and the profitability of fishing for each of the other species, and moves to the species where profitability is greater.

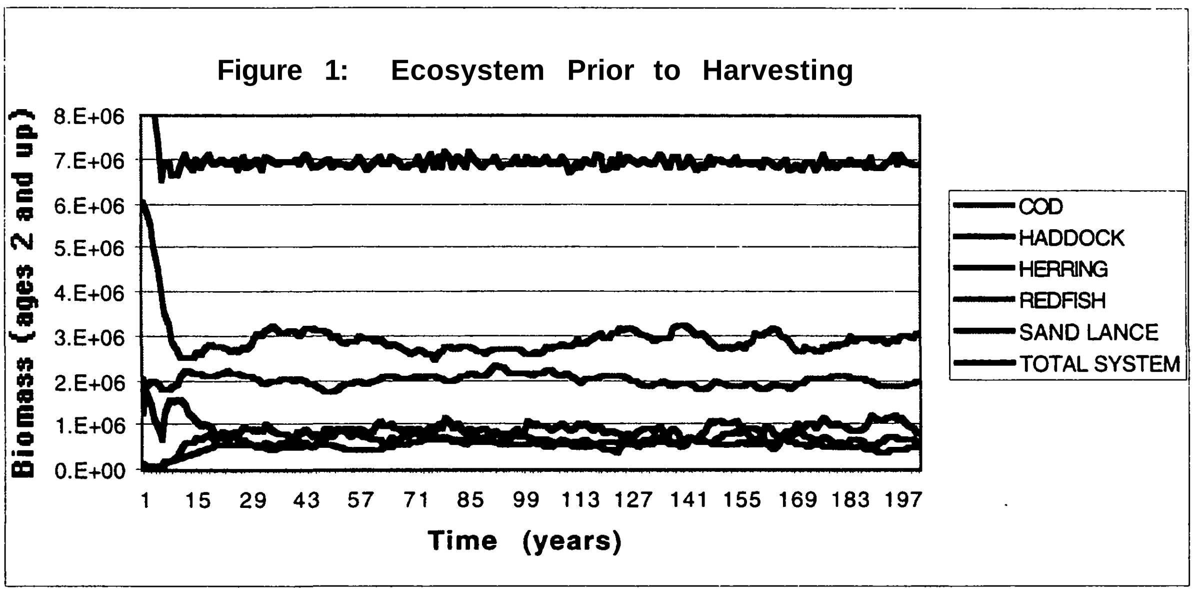
The *Sole Owner* rule assumes a fishing cooperative that owns all of the boats, and determines how to best allocate effort. With the profit maximizing sole owner, decisions regarding whether to add or subtract vessels are based on the results of a search process that compares the owner's past decisions to add or subtract boats, with the results of those decisions (i.e. whether they were profitable or not). The rule uses a 5-year trend to allow the decision-maker to differentiate the signal from the noise, due to the variability of the populations. In the Little Box model, the sole owner will also look at the relative profitability between harvesting the species in Ecosystem I versus harvesting that species in Ecosystem II, and boats will migrate towards the more profitable region. For example, the profitability of fishing for herring in Ecosystem I vs. fishing for herring in Ecosystem II is compared, and the sole owner will move a portion of the boats to the most profitable ecosystem. In the Big Box model, the relative profitability of each species is compared, and the sole owner will reallocate effort to increase profitability. This does not, however, mean that the sole owner will move all of its effort to the most profitable fishery. This is prevented by limiting the amount of effort that can be relocated during a given year. For example, assume a vessel is currently harvesting cod, during the next cycle that vessel will compare its profitability with the profitability of participating in each of the other fisheries, and will move its operation accordingly.

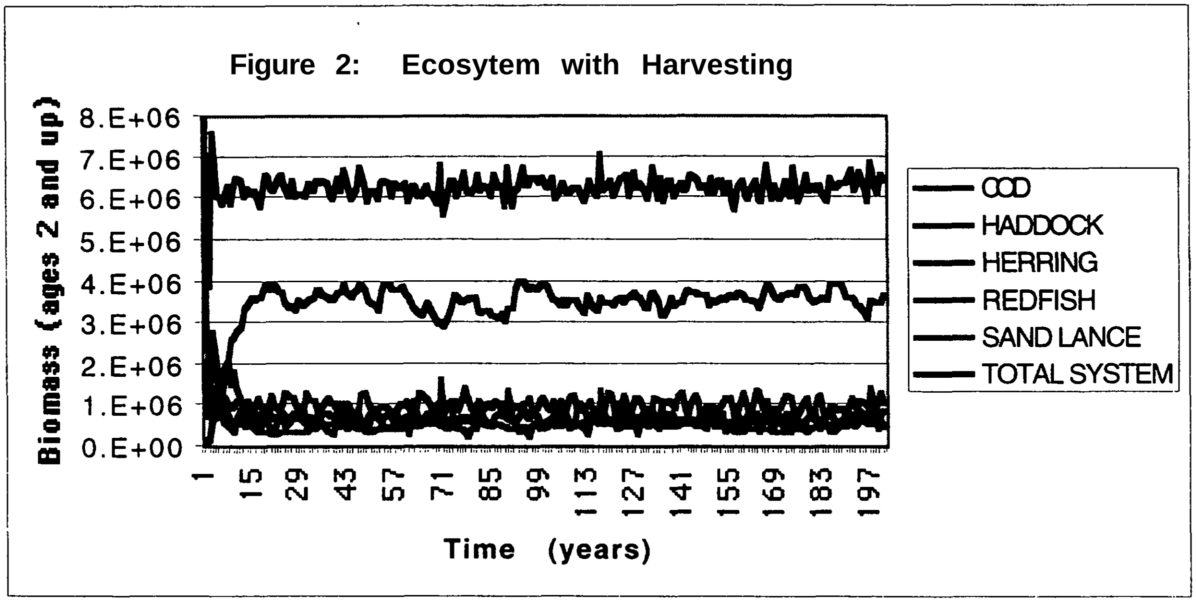
Profitability is calculated as profits per boat. Profits being the total revenue generated minus the total costs. Revenue is simply the total catch (pounds harvested) multiplied by the price per pound. Catch is a function of the number of boats, the available harvestable biomass, and the vessel's efficiency. Harvesting efficiency is a function of the total biomass available for harvest. As the total harvestable biomass increases, the vessel's harvesting efficiency also increases. Harvesting efficiency is the same for each species in each ecosystem. Total costs are a function of the number of boats and the operation costs per vessel. Price per pound and operation costs per vessel are held constant.

Baseline conditions

At baseline conditions with no harvesting, the species are highly variable and exhibit compensation. However the overall biomass of the system is stable (Fig 1). The system is energy efficient, as the total biomass of the system is stable, and the individual populations act as if they are food limited.

Under harvesting conditions, the biomass of the individual species is reduced and variable, and the system becomes more variable compared to the unfished state (Fig 2). Additionally, as expected, sand lance dominates the system when fishing occurs.





Preliminary Results

Wealth, accumulated profits, was used an indicator of benefits generated to society. Additionally, since profits are a function of the harvestable biomass available, wealth is also a good indicator of the health of the resource. The amount of wealth generated in the open access regime was significantly different compared to the wealth generated under the sole owner (Fig 3). Decision making by a sole owner, as expected, was economically and biologically superior to open access management.

However, contrary to our expectations, no significant difference was observed between Big Box and Little Box management (Fig 3). That is, the sole owner modeled here receives sufficient feedback regardless of which management approach is used.

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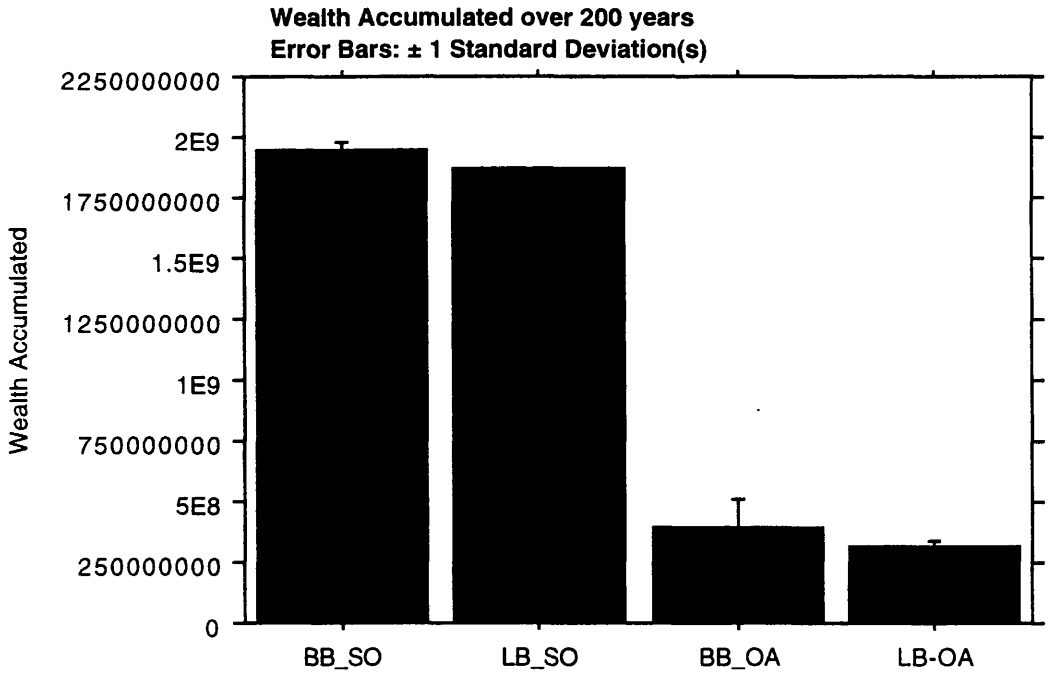

Figure 3: Average wealth accumulated in the two ecosystems over 200 years under different management regimes. Big box and sole owner (BB_SO), Little box and sole owner (LB_SO), Big box and open access (BB_OA), and Little Box and open access (LB_OA).

Discussion

One concern we have regarding these results is that the sole owner here is assumed to have perfect knowledge of the biology and the economic status of the resource. It receives accurate information, which it is then able to analyze and use to make a decision within a timely manner. It is also able to implement that decision immediately. This is not realistic of what could happen with a "real world" sole owner situation. Rarely does a resource manager have completely accurate, up-to-date information on which to base its decisions. Furthermore, once a decision is made, there is a period of time before the decision can be implemented.

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It is very likely that the model, as it currently exists, simplifies the feedback problem. Two changes need to be made to make feedback more imperfect. This is necessary in order to make the model more realistically simulate the feedback problem. First, the species should probably be made more variable. Currently, the species are relatively variable, compared to the system level, but are still somewhat stable compared to what exists in the natural marine environment. Additional variability could be achieved by increasing the randomness of the density-independent mortality that occurs at age one (e.g make recruitment more variable).

Secondly, the ability of the sole owner to make and implement decisions should be more difficult. The time it takes for the sole owner to receive information could be delayed, as could the time it takes for it to implement a decision. Additionally, the sole owner could base its decision on "old" information. This would effectively decrease the quality of the information.

Once the ability of the sole owner to make decisions is made more imperfect, we predict that the Big Box approach to management will result in more sufficient feedback compared to the Little Box approach. Again, this is because more stability exists at the system level than at the species level.

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