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Working towards consensus: application of shellfish carrying capacity in management of Rhode Island aquaculture.

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Abstract

Oyster farming is growing rapidly in Rhode Island, expanding in a six year period (2001-2007) from a $300,000 industry on 18 farms to a $1.6 million industry on 30 farms. This expansion has wild clam harvesters concerned about the loss of fishing grounds. In response to this resource use conflict, the RI Marine Fisheries Council, which comments to the state aquaculture permitting authority (Coastal Resource Management Council (CRMC)) on aquaculture lease applications, announced that they would refuse to consider any new aquaculture leases until a long-term aquaculture plan was in place. The fundamental question is what, if any, limits should be placed on shellfish aquaculture in RI? The CRMC revitalized its Working Group on Aquaculture Regulations (WGAR), which consists of representatives from the aquaculture and wild harvest industries, regulators, academicians, and non-governmental organizations. The WGAR reviewed several issues of importance for a long-term aquaculture plan: water quality, disease, aquatic nuisance species, physical impacts of aquaculture gear,

essential fish habitat, carrying capacity, and discussed a future ecosystem approach to aquaculture. The issue that drew unanimous interest was carrying capacity – what is the ecological carrying capacity for oyster aquaculture in Narragansett Bay and RI's coastal ponds? We present a framework of monitoring and modeling to guide management of shellfish aquaculture. Given that the problem of user conflicts facing RI also faces other areas, we regard this as an excellent opportunity to advance the process of modeling ecological carrying capacity with the involvement and assistance of stakeholders.

Introduction

Marine shellfish aquaculture is one of the most environmentally beneficial forms of marine aquaculture, but user conflicts still exist between shellfish culturists, traditional fishers, and other users of marine resources. These user conflicts can be minimized by exercising the three principles of aquaculture outlined by Soto (2007):

i) Aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity,
ii) Aquaculture should improve human well-being and equity for all stakeholders,
iii) Aquaculture should be developed in the context of other sectors, policies and goals.

The aquaculture industry in Rhode Island, USA, 99% of which is oyster culture (Alves 2007), is currently in a unique position to explore viable management strategies that promote these three principles (Table 1). The industry is growing at a rapid rate and local shellfishermen and state regulators recognize the need for a possible change in regulations that will guide future growth or possibly limit it. Inaction or missteps could threaten the sustainability of the industry and ecosystem.

Rhode Island is developing a long-term aquaculture plan. The question central to defining this plan is: What is the carrying capacity for shellfish in RI coastal waters? Carrying capacity will be determined by using a mass-balance modeling technique similar to that of Jiang and Gibbs (2005) and through stakeholder involvement. Stakeholder input is critical in identifying acceptable versus unacceptable impacts on the ecosystem. It is here that we present the process for determining carrying capacity to create a scientifically-valid and stakeholder-approved long-term aquaculture policy. The approach and process being used to define the plan, we believe, are unique and may be easily transferable to other states or countries. One can view the issue of determining the limits to growth of aquaculture in RI in two ways: either as a tempest in a very small teapot or as the wave of the future. Because Rhode Island is a small state with many user conflicts in its coastal waters, it represents an excellent test case of how regulators should proceed in managing aquaculture growth.

Table 1. Application of Soto's (2007) guiding principles in developing Rhode Island's long-term aquaculture plan.

Soto's Principles	RI's Process	Expected Outcome
1: Aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity	Determine carrying capacity through mass-balance ecosystem modeling	Aquaculture plan that controls the growth through state regulations and guidelines that were developed using best available science and stakeholder input.
2: Aquaculture should improve human-well being and equity for all stakeholders	Stakeholders and science define "acceptability"	
3: Aquaculture should be developed in the context of other sectors, policies and goals	Stakeholder involvement from many sectors: aquaculture, wild harvest, recreational fishermen, riparian land owners, environmental advocates and management	

History

In Rhode Island, a history of conflict exists between oyster culture and the wild capture fisheries, dating back over a century. In the early 1900's, oyster leases occupied about one-third of Narragansett Bay. When oyster culture collapsed for a variety of reasons, the leaseholders retained their exclusive rights to the grounds and charged clam fishermen to harvest the wild clams on their leases, leading to enmity and violence. Consequently, in the 1970's, perspective oyster farmers faced vigorous opposition from clam diggers who had heard the history from fathers and grandfathers. In early 2000, the RI Coastal Resources Management Council (CRMC) convened a Working Group on Aquaculture Regulations (WGAR), which was composed of representatives of both aquaculture and wild fishery industries, regulators, and academicians. CRMC is the lead aquaculture permitting authority in the state, receiving input from the RI Department of Environmental Management (DEM) and the RI Marine Fisheries Council (MFC), as well as appropriate federal agencies. The purposes of the CRMC-WGAR were to build understanding between the two industry groups, to explore means by which the two industries could coexist, and to recommend changes to laws or regulations that would enhance that coexistence. The most important outcome of these efforts was a drastic overhaul of regulations based on the recognition that cultured crops were the property of the farmer, not natural resources of the state. Another important output of that effort was a GIS map of Rhode Island's coastal waters delineating usage by recreational and commercial fishers (Alves, personal communication). A third important change was the development of a preliminary determination hearing that allowed prospective farmers to hear about potential conflicts before they submitted a full application. This process and the GIS map enabled prospective growers to identify areas where conflicts were minimal allowing the permitting of more oyster culture operations. Following its success, the CRMC-WGAR entered a period of dormancy. During that time, oyster culture expanded from a $300,000 industry on 18 farms in 2001 to a $1.6 million industry on 30 farms in 2007 (Alves 2007). RI's aquaculture industry may be small on a global scale, but the user conflict is typical of any high-use system. Much of the expansion took place in the coastal ponds along RI's south shore, areas that are subject to multiple uses such as commercial and recreational fishing and boating. Permit applications were also heavily scrutinized by affluent riparian landowners.

In 2007, the RI Marine Fisheries Council, which comments to CRMC on aquaculture lease applications, announced that they would refuse to consider any new aquaculture leases until a long-term aquaculture plan for RI was in place. The fisheries managers maintained that it was impossible to determine the environmental impact of the shellfish aquaculture industry in the aggregate unless they knew how much of the state's waters could be devoted to this use. The fundamental question is what, if any, limits should be placed on shellfish aquaculture production in RI (currently the only type of aquaculture in RI waters). This refusal was in response to pressure from commercial clam diggers that feared the loss of fishing grounds.

In response to this demand, the CRMC-WGAR was revitalized and the membership was expanded to include representation from environmental groups and riparian landowners. In early discussions, the CRMC-WGAR decided to approach the problem first from a scientific and regulatory perspective before tackling the social, user-conflict issues. This decision was the result of deliberations of the whole group, including both industries. The CRMC-WGAR Subcommittee on Biology produced a report on the issues identified by the group as necessary to understand before proceeding: water quality, disease, aquatic nuisance species, physical impacts of aquaculture gear, essential fish habitat, carrying capacity, and an ecosystem approach to aquaculture (http://www.crmc.state.ri.us/projects/aquaculture.html). As the CRMC-WGAR considered all these issues, the one that drew the most attention and appeared to be most critical in developing a sustainable long-term aquaculture plan was carrying capacity – the whole group wanted to know what is the carrying capacity for oyster aquaculture in Narragansett Bay and RI's coastal ponds?

Carrying Capacity

The term "carrying capacity" has been used with varying definitions to describe the quantity of something that can be added to an ecosystem before some undesirable impact occurs. Small-scale shellfish aquaculture has been shown to have many ecological benefits (Shumway *et al.* 2003), but at some point too much of a good thing invariably has negative consequences. Where to draw that line can be a subjective question that depends on which specific consequences are of concern.

In the simplest of terms carrying capacity is determined by the amount of shellfish in a given body of water in relation to the flushing or exchange rate of the water in that basin. When the combined filtration capacity of a population of shellfish consumes an excessive proportion of the phytoplankton in that system before tidal flushing (and the natural reproduction of the phytoplankton in that system) can replenish that plankton, then the shellfish start to dominate the energy flow in that system (Dame and Prins 1998).

Inglis *et al.* (2000) distinguished four types of carrying capacity: physical, production, ecological and social, which are increasingly complex to understand and model.

i) **physical carrying capacity** — the total area of marine farms that can be accommodated in the available physical space.
ii) **production carrying capacity** — the stocking density of bivalves at which harvests are maximized. The "optimized" level of production of the target species. (This has usually been the carrying capacity calculated for production sites around the world, based solely on industry's needs.)
iii) **ecological carrying capacity** — the stocking or farm density above which unacceptable ecological impacts begin to manifest. From a practical standpoint this process begins with the definition of components of interest (e.g., species or habitats) and acceptable levels of change for each of these.
iv) **social carrying capacity** — the level of farm development that causes unacceptable social impacts.

Physical and production carrying capacity are inappropriate when discussing sustainable development in a multiple use environment. Our focus is on ecological and social carrying capacity which considers the entire ecosystem and the societal pressures and demands on that ecosystem. Ecological carrying capacity can be determined through modeling (McKindsey *et al.* 2006, Jiang and Gibbs 2005). Social carrying capacity can be determined through stakeholder involvement and feedback that is incorporated into ecosystem models (McKindsey *et al.* 2006, Swart and van Andel 2008). RI is developing a new approach in efforts to link ecological and social carrying capacity.

Linking Ecological and Social Carrying Capacity

Societal constraints should guide ecological carrying capacity models (McKindsey *et al.* 2006). An ecological model alone offers tremendous insight and guidance to sustainable use of the system. However, there are almost always instances where societal constraints, such as user conflicts, restrict environmental managers from obtaining an ecological ideal, thus settling for a realistic compromise. For example, the acceptable stocking density defined by ecological carrying capacity may exceed that defined by social carrying capacity.

Rhode Island regulation prohibits aquaculture in areas that impede navigation or diminish aesthetic value which is a societal limit to the available area for aquaculture and thus stocking density. Ecological carrying capacity models do not, necessarily, take such societal constraints into account. It is only through a feedback process (McKindsey *et al.* 2006) between ecological and social carrying capacity that an ultimate compromise can be reached thereby mitigating user conflict. We give a brief review of prior work that has guided our approach as well as explain our specific modeling efforts and stakeholder involvement in determining ecological and social carrying capacity for the purpose of developing a long-term aquaculture plan.

Modeling Carrying Capacity

Much effort has been made at modeling production carrying capacity, as culturists wish to know how much culture they can put in an area before they reach negative effects on their own production. Ecological carrying capacity is more complex and also subject to debate about what are acceptable versus unacceptable impacts. The development of shellfish aquaculture on a large scale in New Zealand has given rise to useful concepts and model development to determine the acceptable limits to shellfish aquaculture production in the Marlborough Sounds region. Gibbs (2004) began by examining the relationship between shellfish farms and fishery resources, noting that primary and secondary productivity that would normally provide the food-web support for commercial fisheries could instead be diverted to shellfish production (this concept was already proposed more than 25 years ago by Lapointe *et al.* (1981) and Tenore *et al.* (1982) for mussel production in Spain). Gibbs specifically considered three types of interactions between bivalve culture and fisheries: a) shellfish farms either attract or displace natural fish populations, b) shellfish consume the eggs and larvae of fishes, and c) food webs are altered so that production is by farmed shellfish rather than natural fisheries. Under item c), he used food-web models to try to estimate how much shellfish aquaculture could take place before energy cycling in the system became dominated by that culture. Jiang and Gibbs (2005) advanced the food-web modeling approach using the Ecopath model to make more quantitative predictions of carrying capacities, finding that the production carrying capacity for cultured shellfish for Golden and Tasman Bays in New Zealand was 310 tons/km^2/yr, but the ecological carrying capacity was only 65 tons/km^2/yr. To our knowledge, this is the first time Ecopath has been used to determine ecological carrying capacity of shellfish aquaculture. We consider this a seminal work and one that we wish to emulate in our work in Rhode Island.

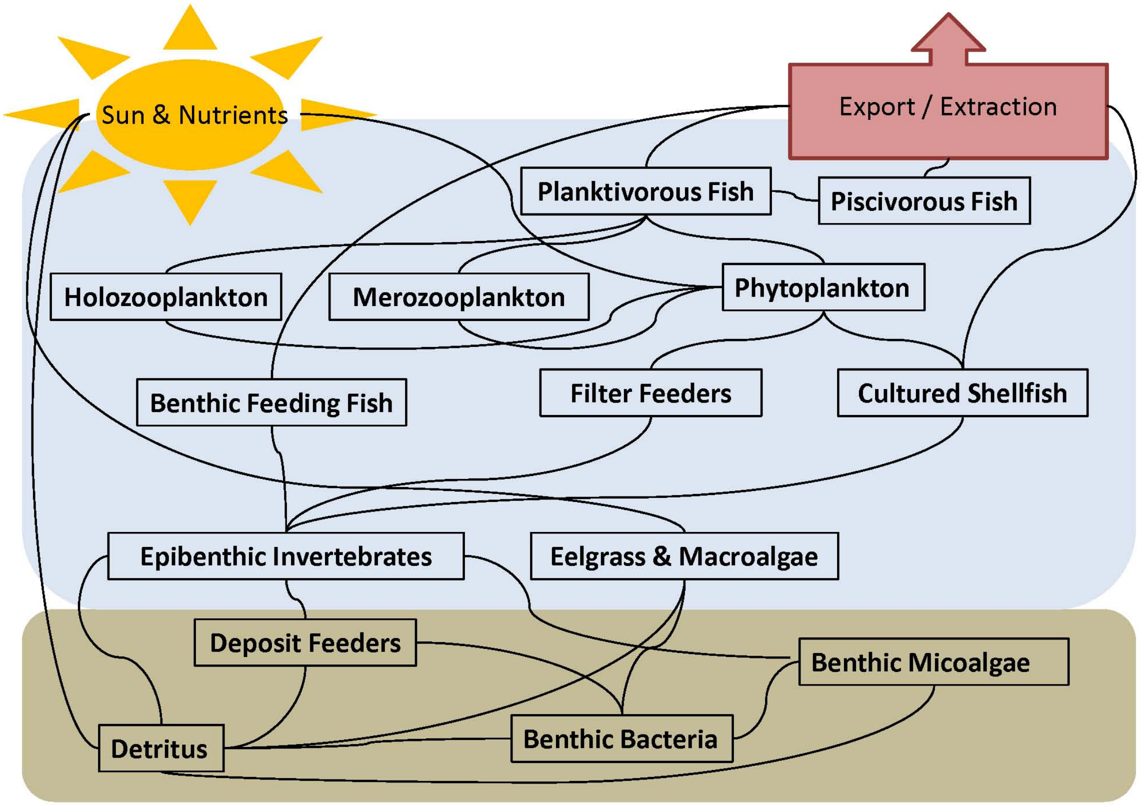
We utilize and advance the work of Jiang and Gibbs (2005) by applying the Ecopath food-web model to Rhode Island's coastal ponds and Narragansett Bay. Fortunately, a great deal is known about the biology and productivity of Narragansett Bay and the coastal ponds in southern RI, where the aquaculture takes place, due to sampling programs of state agencies and academicians over the years. The RI DEM has had monitoring programs for finfish and shellfish in the coastal ponds and Narragansett Bay for many years to provide data for fisheries stock assessments. Both Narragansett Bay and the coastal ponds have been subject to eutrophication as coastal development has led to increased nutrient runoff; the eutrophication problem has been well studied (Nixon *et al.* 1995, 2005, Nixon 1995, Lee 1997, Ernst *et al.* 1999, Carey *et al.* 2005, Nixon and Buckley 2007, Costa-Pierce *et al.* 2008). The abundant data and reports from environmental surveys will be used to parameterize the Ecopath model.

Ecopath with Ecosim is a modeling approach designed specifically for analysis of exploited aquatic ecosystems (Christensen and Walters 2004). Primarily intended for use in examining fisheries impacts on ecosystems, the Ecopath component is the analysis of ecosystem trophic mass balance, whereas the Ecosim component allows for modeling of projected scenarios over time. Another module called Ecospace comprises a spatial map grid in which Ecosim can operate with spatial heterogeneity. The history of this modeling approach dates back to the early 1980's and the models have become more refined and valuable in recent years. As fisheries and other forms of resource management have focused more on an ecosystem approach, many scientists have found this modeling approach to be extremely useful and it was voted by the U.S. National Oceanic and Atmospheric Administration (NOAA) as one of the top 10 breakthrough achievements (www.ecopath.org). Rather than providing outputs at the population level of biological organization typical of fisheries models, the Ecopath with Ecosim modeling approach provides outputs at the ecosystem level, reflecting food-web linkages, energy cycling, and changes in biomass of each species group defined in the model.

The goal is to develop an Ecopath model for both Narragansett Bay and the coastal ponds. To our advantage, an Ecopath model has previously been constructed for Narragansett Bay (Monaco and Ulanowicz 1997). The model was originally built for the purpose of an ecosystem comparison of three major North Atlantic bays in the US: Narragansett Bay, Chesapeake Bay, and Delaware Bay and is now 11 years old (Monaco and Ulanowicz 1997). Before the model is functional for the purpose of determining the ecological carrying capacity of cultured shellfish, the model needs to be re-verified with current data and slightly modified. The modification entails creating a species group specific for cultured shellfish which are currently embedded in the species group for filter feeders. The Narragansett Bay model will also provide the basis for the coastal ponds model (Figure 1). Since this is a trophic food-web model and the food-web structure of both systems is very similar, parameter inputs for both models will also be similar.

There are nine coastal ponds along the southern coast of Rhode Island. Our intent is to create one generic model appropriate for all the coastal ponds (Figure 1). The major difference between the coastal ponds is not biological in nature and therefore will not impact the food-web structure. Rather, the difference between ponds is physical in nature. Some of the ponds have restricted flushing and the others have high flushing through a stabilized breachway. After the generic pond model has been verified with field survey data, two variations of the pond model can be developed; one for the ponds with restricted flushing, and one for ponds with high flushing. The impact of flushing must be characterized for at least one species group, preferable phytoplankton, prior to the modeling effort. Knowing the impact of flushing rate on phytoplankton and using the forcing function in Ecopath, differences in flushing rate can be modeled. With additional time and expertise, it would be ideal to link the Ecopath food-web model with a physical model of flushing rates.

Figure 1. Conceptual diagram of Rhode Island salt pond food-web and ecosystem model.



While only the basic Ecopath model is needed to determine carrying capacity, temporal and spatial variability will be explored using the two simulation components, Ecosim and Ecospace. Changes in biomass can be observed over monthly time-steps, or within localized habitats. Ecosim and Ecospace offer a finer resolution with which to observe change. Ecopath is only a snapshot of a one-year average for the entire system.

Stakeholder Involvement – What is acceptable?

The question for resource managers becomes: What is the appropriate proportion of an ecosystem's primary production that should go to cultured shellfish as opposed to some other component of the ecosystem such as zooplankton? There is no simple objective answer to this question. When the biomass of shellfish are able to clear the volume of a basin faster than the water is replenished by tidal action there is the possibility that the shellfish will regulate the concentration and character of the primary production at the expense of the planktonic food web (Dame 1996).

While we greatly admire the work of Jiang and Gibbs (2005), we are concerned about the social consequences of a small group of academicians applying Ecopath to aquaculture in Rhode Island and presenting "the answer" to the concerned stakeholders as a *fait accompli*. The Biology Subcommittee of the CRMC-WGAR has made strides in educating members of the WGAR on the ecological interactions of shellfish aquaculture and wild fisheries, both positive (cages provide habitat for juvenile fish) and negative (overly concentrated culture can degrade the benthos). The WGAR has operated long enough that there is a certain level of understanding and trust among members, so that civil discourse and an attitude of working together predominate. The WGAR has accepted the report of the Biology Subcommittee on the aquaculture issues in RI, furthering the involvement of the stakeholders in the scientific process.

Our principle is that our search for ecological carrying capacity will be guided by the need to define the "unacceptable" impacts of oyster aquaculture on the environment. The CRMC-WGAR consists of both scientists and non-scientists. Ecologically we will define "unacceptable change" using a mass-balance Ecopath model by increasing the biomass of cultured shellfish until there is an unacceptable change in energy flow between groups (Jiang and Gibbs 2005) resulting in an 'unbalanced' model. The biomass of cultured shellfish at which the model becomes unbalanced will define the upper limit to what is acceptable – the ecological carrying capacity. However, stakeholders may decide that the ecological carrying capacity is too high and want to manage at a lower level – the social carrying capacity. In this sense, acceptability will be bound by the Ecopath model at its upper limit (ecological carrying capacity) and by stakeholders at some lower limit (social carrying capacity), thus fulfilling the bounds of acceptability and supporting Soto's (2007) principles of aquaculture (Table 1) and ensure environmental resilience capacity, human well-being, stakeholder equity, and honor current policies and goals of other sectors.

It is also possible that stakeholders may decide that the ecological carrying capacity set by the Ecopath model is too low and wish to have more aquaculture than the ecosystem can support. In this case, we anticipate much debate and deliberation between the aquaculture industry, wild harvesters, management, and environmental advocates. In order to avoid such heated debates, we plan to make the modeling procedure transparent to stakeholders so that they understand and trust the validity of the model and will be more likely to incorporate the results into their management plan.

Modelers involved in this project will brief the CRMC-WGAR at their monthly meetings on the status and findings of the Ecopath model. We plan to hold a series of at least four meetings. The objective of the first meeting will be to gain stakeholder understanding and agreement on the conceptual food-web diagram and species groups (Figure 1) that will be used in constructing the model (Table 2). We regard this as an excellent opportunity to educate the stakeholders on ecosystem linkages and the importance of lower trophic groups that are typically over-looked by a lay audience such as detritus, benthic bacteria, and benthic microalgae. Modelers will explain the ecological reasoning of choosing the 14 groups suggested in the conceptual diagram (Figure 1). Stakeholders will have an opportunity to make additional suggestions and may wish for there to be more or fewer groups. We anticipate that the wild harvesters may request a group specifically for hard clams (*Mercenaria mercenaria*), for example, or that the commercial fishermen may request a group specifically for winter flounder (*Pseudopleuronectes americanus*); however, breaking the model into specific groups will not provide any additional clarity in determining the ecological carrying capacity and will only complicate and clutter the Ecopath model. At the conclusion of the first meeting, we hope that all stakeholders understand and agree on the food-web diagram that will be the basis for the diet matrix and species groups used in creating the Ecopath model.

Table 2. Stakeholder involvement in creating the Ecopath model.

Meeting	Academicians will present to the CRMC-WGAR the…
1	conceptual food-web diagram (Figure 1).
2	sources of data used for parameter inputs to the model.
3	balanced and validated model.
4	ecological carrying capacity.

The objective of the second meeting will be to present the sources of data that will be used to estimate the biomass, production/biomass, and consumption/biomass input parameters to the Ecopath model (Table 2). All sources of data will be presented along with the variability within and between data sets. In the case of multiple data sources for a single parameter, the mean will be used and the minimum and maximum datum will be noted as the lower and upper bounds (a sort of “confidence interval”) by which the parameter may vary while balancing of the model. At the conclusion of the second meeting, we will evaluate stakeholder understand and obtain agreements on data sources and how they will be used to derive parameter inputs for the Ecopath model.

The objective of the third meeting will be to present the balanced and validated model (Table 2). We anticipate that the model will not be balanced on the first attempt and that the modelers will need to adjust the input parameters within the bounds of the confidence interval. These adjustments will all be recorded and justified to the stakeholders. After the model is balanced, it will be validated against field surveys and historical trends. At the conclusion of the third meeting, we will evaluate stakeholder understanding of the general process in creating the model, obtain agreements that it is valid, and their approval of using it to determine the ecological carrying capacity of cultured shellfish.

The objective of the fourth meeting is to present the results – the ecological carrying capacity of cultured shellfish. Since the stakeholders were involved in every step of creating the model, understood the process, and accepted the progress made at each meeting, it will be difficult for them to argue against the result. At this point, the CRMC-WGAR will need to decide if the model-derived ecological carrying capacity is acceptable, or if they will consider additional societal impacts in agreeing on an acceptable limit to aquaculture and creating a long-term aquaculture plan.

Although ecological carrying capacity can be determined using only the Ecopath component, the CRMC-WGAR may request that we continue modeling using the Ecosim and Ecospace simulation components to explore temporal and spatial variability. Ecosim and Ecospace were designed for the purpose of addressing management questions and predicting change in ecosystem structure over time and space. We believe that it will be in stakeholders best interest to continue exploration of the temporal and spatial impact of increased cultured shellfish biomass.

A permanent record of the process leading up to the final product will be recorded in the CRMC-WGAR meeting minutes. Stakeholders will also always have the opportunity to provide written comments for the record on this process. In the end, we will have model outputs that reflect a broad consensus of stakeholders and that are scientifically valid (Table 1). Given the uniqueness of this process, we plan to describe the process and its outcome in a series of publications for aquaculture regulators, coastal managers, and the stakeholders' organizations themselves.

Conclusion

Developing a sustainable long-term management plan is a difficult course to navigate. Recent advances in the measurement and application of carrying capacity provide some guidance. Modeling ecological carrying capacity with feedback from stakeholders in the system holds the most promise for meeting Soto's (2007) three principles of aquaculture, but due to its newness, is also the least understood and practiced. Rhode Island is an excellent venue for testing this approach so that it might be made available to those in other areas, who see the value of stakeholder involvement in a science-based effort to find the proper limits to aquaculture in their local waters.

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