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Research, part of a Special Feature on A Systems Approach for Sustainable Development in Coastal Zones

Progress Toward Sustainable Mussel Aquaculture in Mar Piccolo, Italy

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ABSTRACT. Mar Piccolo of Taranto is an estuarine basin heavily exploited for commercial mussel (*Mytilus galloprovincialis* L.) farming. The historical renown of the Taranto mussels has suffered over the last decade following policy decisions to expand the mussel farms and to relocate a portion of the urban sewage to an outfall outside of Mar Piccolo. The resulting decline in mussel quality and the quandary of how to restore stability to Taranto mussel production became the focal issue for our application of the systems approach framework (SAF). We simulated the ecological, economic, and social interactions that affect mussel production. Stakeholders and mussel farmers contributed by participating in meetings during the entire exercise. Our simulation analysis provided them with a means for understanding the effects of policy scenarios on the system. We present three aspects from our initial results that demonstrate the value of the SAF, as: (1) an operational model to monitor and better research the status of the ecosystem, (2) a management tool to evaluate sustainable mussel farming strategies, and (3) an opportunity for improved communication with and engagement of stakeholders, policy, and the public. The application has also raised important questions about how the food chain is controlled, what could be changed to stabilize the ecosystem to a higher level of productivity, and what role the public and policy could play in promoting sustainable development.

Key Words: *aquaculture; bioeconomical modeling; carrying capacity; estuarine ecosystem simulation; Mar Piccolo; stakeholder involvement; sustainability*

INTRODUCTION

Taranto coastal zone

Ecosystem

The Mar Piccolo is a shallow, nearly enclosed basin with an area of 21 km² (Fig. 1). It consists of two sub-basins, Seno I and Seno II, with maximum depths of 13 and 10 m, respectively. The construction of a 12-m deep navigational canal in the early 1900s created a two-way exchange with the Mar Grande, a partially enclosed third basin that directly connects with the Gulf of Taranto. During the 1970s, a steel factory installed a large cooling water intake system that removes 120,000 m^3 d^{-1} of water from Mar Piccolo and discharges it into the Gulf of Taranto (ILVA 2009). Land runoff derives from numerous submarine springs, small streams, sewage outfalls, and some industrial discharges averaging about 300,000 m^3 d^{-1} (A. Bisci, *personal observation*). This additional outflow quickened the circulation and reduced flushing times to two to three weeks. The phytoplankton community normally consists of three groups, with diatoms comprising about two-thirds and dinoflagellates and phytoflagellates make up the remaining third in fairly equal amounts. The only existing data on phytoplankton biomass is the annual (1999-2000) mean value of 126 mg C m^{-3} (Caroppo et al. 2006). Occasional potentially toxic blooms have occurred, involving diatoms *Pseudo-nitzschia* spp. and dinoflagellates *Dinophysis* spp. and *Alexandrium minutum*. Hypoxic events occur during summer when slower circulation, warmer temperatures, and reduced

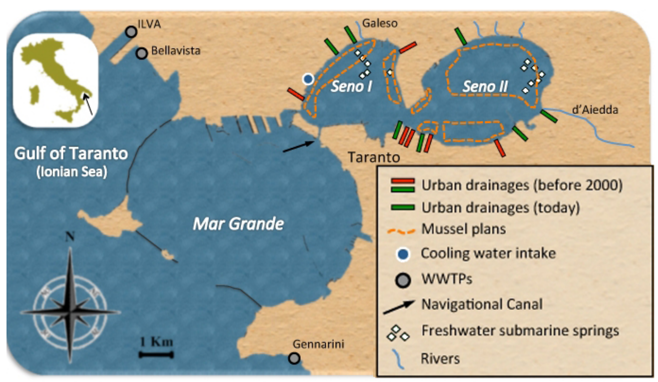

Fig. 1. Map of the Taranto Sea system (northern Ionian, Mediterranean Sea) including the two sub-basins of Mar Piccolo, Mar Grande, and the nearby Ionian Sea (Gulf of Taranto). Note that the Bellavista and Gennarini wastewater treatment plants (WWTPs) closed in the period 2000-2006 whereas ILVA is mainly an industrial discharge. The simulation period of the model concerns the distribution and extension of the mussel farms in Mar Piccolo during 2002-2004. In sub-basin Seno I mussel farms covered 26% of the total area of 8.3 km² whereas in sub-basin Seno II they covered 66% of the total area of 12.4 km².

volume in the lower layer cause the bottom respiration to have a greater effect. These events stress the benthic communities and the more deeply placed mussels, which extend only to 5 m.

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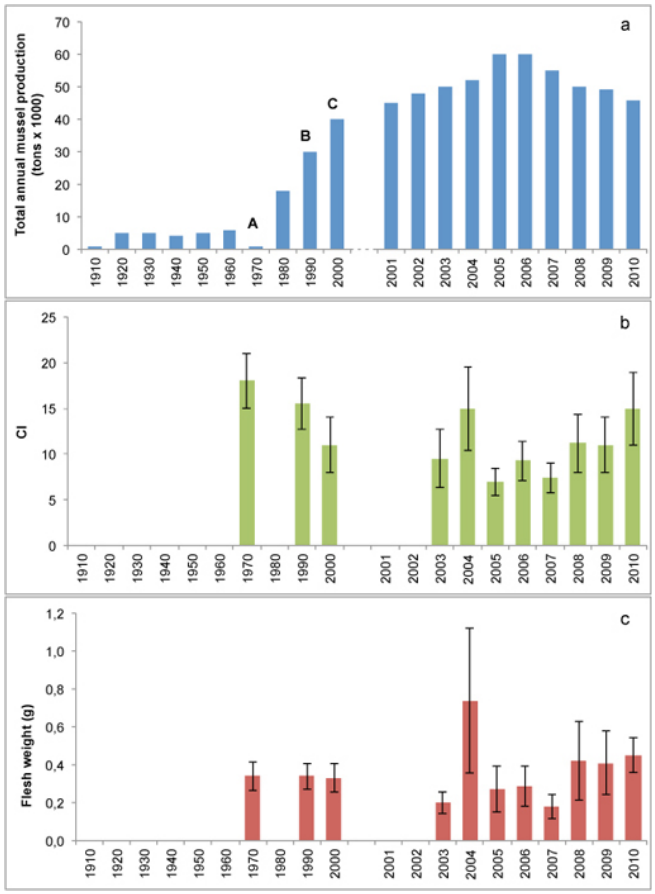
Mussel culture

Mar Piccolo (MP) has long been known for the quality of its farmed mussels (*Mytilus galloprovincialis* L.; Parenzan 1984, Pastore 1993). Mussel farming was the main economic activity in Taranto up until the farm closures in the 1970s following a cholera outbreak. The traditional mussel farming was artisanal and the dominant technique involved suspending mussels from wooden stakes driven into the sea bottom. After the cholera closures in 1973 and throughout the 1980s, farms were expanded to accommodate unemployed industrial workers. During the 1990s, the use of long-lines replaced the stakes (Fig. 2a), and production increased to a maximum of ~ 60,000 tons y^{-1} in 2005-2006. During 2000-2006 two policy decisions were implemented: (1) 6 out of 12 sewage outfalls were progressively relocated to Gennarini in the Gulf of Taranto (Fig. 1) to reduce bacterial exposure, and (2) more licenses and concessions were granted to allow mussel farmers to further extend their farmed areas to increase production. Instead it began to decline after 2006 to 40,000 tons y^{-1} in 2010 and the quality of the mussels, measured by a condition index (CI), the ratio of flesh-to-shell dry weight x 100 (Rainer and Mann 1992), dropped to 50% of its 2004 level (Fig. 2c) then improved somewhat (Figs. 2b,c).

Traditionally, the MP mussel culture consisted of individual family-run cooperatives, and there has never been a collaborative management plan among them. The total enterprise consists of 37 individual cooperatives, employing about 900 farmers (600 part-time), over a total legal farm area of ~10 km². They are regulated by national and regional laws (Table 1) and controlled by local authorities (Table 2), most recently by the "Centro Ittico Tarantino." Mussel farming practices vary somewhat depending on the individual cooperative and its location in the basin. Before marketing, all mussels require purification, which includes moving them to a designated 'clean-water' area located in Mar Grande. During hypoxic events, the threatened mussels are also transferred to the Mar Grande.

Fig. 2. (a) Changes in Taranto mussel production, (b) quality (expressed as condition index – CI), and (c) flesh weight (expressed as dry weight). Letters in the first panel identify the following events: (A) cholera epidemic (1973); (B) crisis of the heavy industry that made many farmers return to their old occupations; introduction of long-lines; (C) policy changes and illegal occupation of new areas (G. Portacci, *unpublished data*).



SAF simulation

This study reports on an application of the systems approach framework (SAF) in the Mar Piccolo as one of 18 coastal zone systems that participated in the development and testing of the SAF by the EU Project, Science and Policy Integration for Coastal System Assessment (SPICOSA). Hopkins et al. (2011) have described the rationale and methodology of the SAF, which offers information to coastal-zone decision makers by conducting simulation analysis of a policy issue together with scenarios for its resolution while engaging stakeholders and policy in the process.

During our negotiation phase with our participating stakeholder group, it became clear that their main concern was the variability in mussel production and decline in mussel quality. Thus, our policy issue became "how to include mussel culture in a management plan for improving the sustainable use of the Mar Piccolo resources." Implicit in this issue is the evaluation of the carrying capacity of the MP ecosystem to improve the quality of the harvest, the ecosystem health, and the associated positive benefits to the City of Taranto. Several scenarios for simulation analysis were considered for each of the two primary questions: (1) What are the environmental conditions affecting mussel production?; (2) What are the options for improving the sustainable use of the Mar Piccolo? The specific scenarios of these questions evolved during the research and dialogue with the stakeholders.

Our objective is to describe three aspects of our simulation analysis that demonstrate the value of our SAF application and

Table 1. European, Italian, and regional legislation regulating mussel culture in Taranto.

Urban Waste Water Treatment Directive 91/271/EEC	It concerns the collection, treatment, and discharge of urban waste water and the treatment and discharge of industrial waste waters.
Water Framework Directive 2000/60/EC	It commits European Union member states to achieve good qualitative and quantitative status of all water bodies, including marine waters up to one nautical mile from shore, by 2015.
Marine Strategy Framework Directive 2008/56/EC	It outlines a transparent, legislative framework for an ecosystem-based approach to the management of human activities that supports the sustainable use of marine goods and services.
Italian Legislative Decree n. 530 dated 30 December 1992 and subsequent amendments	Implementation Directive 91/4912/ECC and Ministerial Decree 14/10/98 of the Ministry of Health establishes the health regulations that apply to the production and marketing of bivalve molluscs.
Regional Committee resolution n. 785 of 24/06/1999	Legislative Degree n. 131 of 27/01/1992 - implementation of the Shellfish Waters Directive (79/923/EEC) on the quality required of shellfish waters - Verification of conformity with art. 3.
Circular n. 703/3164/1647 dated 20 March 1996 issued by the Ministry of Health	Identification and classification of designated areas for shellfish farming in accordance with the Italian legislative decree n. 530 date 30 December 1992, and subsequent amendments.
Legal Order of Taranto Port Authority N. 703/3164/1647	Designated farming and harvesting areas for bivalve mollusks and other species.
Legal Order of Taranto Port Authority N. 13 of 16/01/2001	Regulations for the application and concession of designated state maritime areas for shellfish farming in Taranto.
Legal Order of Taranto Port Authority N. 107 of 11/04/2005	Anchoring areas of Mar Piccolo and Mar Grande of Taranto are designated.

that potentially could contribute to sustainable management of Mar Piccolo, i.e.,:

1. An operational ecosystem model that describes the environmental conditions necessary for the mussel growth and its responses to changes in external inputs.
2. Options for a management reorganization that would lead to a more sustainable harvest, a higher profit, minimization of illegal harvesting, and more collateral benefits for the citizens of Taranto.
3. An improved collaboration among researchers, policy makers, stakeholders, and an enhanced communication with the public through web-based technologies that could assist the city in pursuing sustainable development.

METHODS

Virtual system

The SAF requires an ability to focus on a specific functionality, i.e., the policy issue, of a system and to analyze how it responds to change (Hopkins et al. 2011). Our virtual system focused on the range of functionalities affecting mussel culture and the associated responses in the social and economic sectors of Mar Piccolo. The conceptual model of the ecological component of Figure 3 illustrates the primary interactions among its main functional components. The economic component is based on the management of MP mussel culture and its response to the variability of the harvest due to environmental conditions simulated in the ecological component (Fig. 4). It is driven by harvest, labor, and capital costs, controlled by the external pricing of mussels, and regulated by local laws. The social component has direct links to the ecological component through the public perception of the ecosystem health and to the economic component through the social benefits derived indirectly from the mussel farming and directly by the local economy that it serves (Fig. 4).

Data requirements

The selection of data needed for the simulation was based on the conceptual diagrams of Figures 3 and 4. Dependent on the data availability and its quality, all inputs required data processing to make them suitable for the simulation, e.g., quality control, editing, patching, and use of surrogate variables. Data and information sources are listed in Appendix 1. The data was used in the simulation to fulfill several purposes:

- Input data characterize the model in terms of time dependence and of external forcing. Meteorological data from a nearby land station provided rain, relative humidity, air temperatures, and wind. Land-runoff data were scarce, i.e., only single annual estimates for stream flows, and were scarcer for their substance loading, i.e., nutrients and particulate organics. All data needed some processing, i.e., quality checks, conversion of time step, and filling of gaps using statistics, literature, and proxies (cf. Caroppo et al. 2008).
- Calibration data for water and biological properties used the most complete oceanographic sequence (2002-2004) to calibrate the 3-yr hindcast model (see Table A.1). Observations of temperature, salinity, and oxygen variables were recorded as a function of depth and vertically averaged for the surface and bottom layers. Sampling for nutrients and particulate matter were only at the sea surface. Point source effluents were only available as annual estimates for about half of the discharge outfalls; and nonpoint sources were estimated through yield factors (Table A.1).

Table 2. Institutional map and stakeholder roles.

Governmental policy makers		
Regional Agency for Environmental Protection (ARPA)		Pollutants control, environmental monitoring, assessment of environmental impact
		Provides technical-scientific support to regional and local authorities
Regional Government		Planning, implementation strategies, classification of farmable areas, sanitary hygienic laws for production and marketing of mollusks
		Water quality for aquaculture
Taranto Province	Environment Department	Industrial drainage site surveys, authorizations, control and mapping
	Productive Department	Support to farms
		Quality promotion and certification
Taranto Municipality	Environment Department	Permits and authorizations for urban drainage structures
	Production Department	Fish marketing management
	Harbor Office (before 2010)	Authorizations, licensing, and control on fish farming operations
	“Centro Ittico” (today)	
Local Sanitary Authority (ASL)		Authorization for urban drainages
		Sanitary controls on the production and marketing of live mussels
		Classification of mussel production and depuration areas
		Labeling of fish products and control system
Customers		
Lecce and Taranto Universities		Academic and research Institutions
Media		Divulgence and communication
Actors		
Harbor Authority		Technical and administrative marine police
Industries		Multinational companies and some pressure groups as protagonists of impacts to seascape
Aquaculture and Fisheries Organizations		Fish farm management

- Process data were insufficient for the validation of several of the more important processes, e.g., mussel growth, primary production, grazing, regeneration, sedimentation, resuspension, etc. These processes were formulated by using mathematical or empirical expressions from the literature and checked whenever possible through proxy data; e.g., chlorophyll *a* data as a proxy for phytoplankton plankton biomass, or farmer's reports to estimate the total harvest tonnage (Tables A.3, A.4, A.5).

- Economic data for mussel farming were difficult to obtain (Table A.6). We estimated the operating costs for the simulation period and data relative to the management from a similar cooperative in another Italian region (Mazara del Vallo, Sicily). Informal interviews were conducted with farmers to obtain other data specific to MP, e.g., number of legal employees and description of farming practices.

The ecosystem model

The organization of the ecological submodel follows the functional cause and effect chain. The functional components representing larger discrete functions within the modeled system are identified (Fig. 5). Each of these components represents a functional cluster of key processes outlined in Appendix 1 (Tables A.1, A.2, A.3). All modeled variables were calibrated to the hindcast data set (2002-2004) by adjusting constant coefficients to achieve best agreement in variability and time-averages of the observed data. No data-fitting techniques were used to update the models during the 3-yr period. The current version of the model consists of three subcomponent models (PhysChem, Phytoplankton, Mussel), which are linked through a file-input-output iterative procedure.

Physical-chemical

For the PhysChem submodel, we adapted the thermohaline exchange method (Hopkins 1999, 2001) to calculate the two-way exchange and the internal salinity values of the upper and lower layers of each basin. An average pycnocline depth was used for both basins (5 m and 4.5 m), which corresponds to the annual average Secchi depth and, we assume, to the average euphotic depth. The external inputs required for the exchange calculation are the salinity profile in Mar Grande and the daily freshwater balance of Mar Piccolo. Because the exchange depends directly on the difference between the concentration of freshwater inside and outside the basin, a good model agreement with observed interior salinities implies also a good calibration for the exchange with Mar Grande and between layers, i.e., through conservation of salt.

The exchange model also provides the vertical processes of entrainment and diffusion that control the distribution of the

Fig. 3. Conceptual diagram of the ecological component of the simulation model showing inputs and key interactions among the main functional components and processes. The environmental compartments considered are the upper and lower water column layers and the bottom sediments.

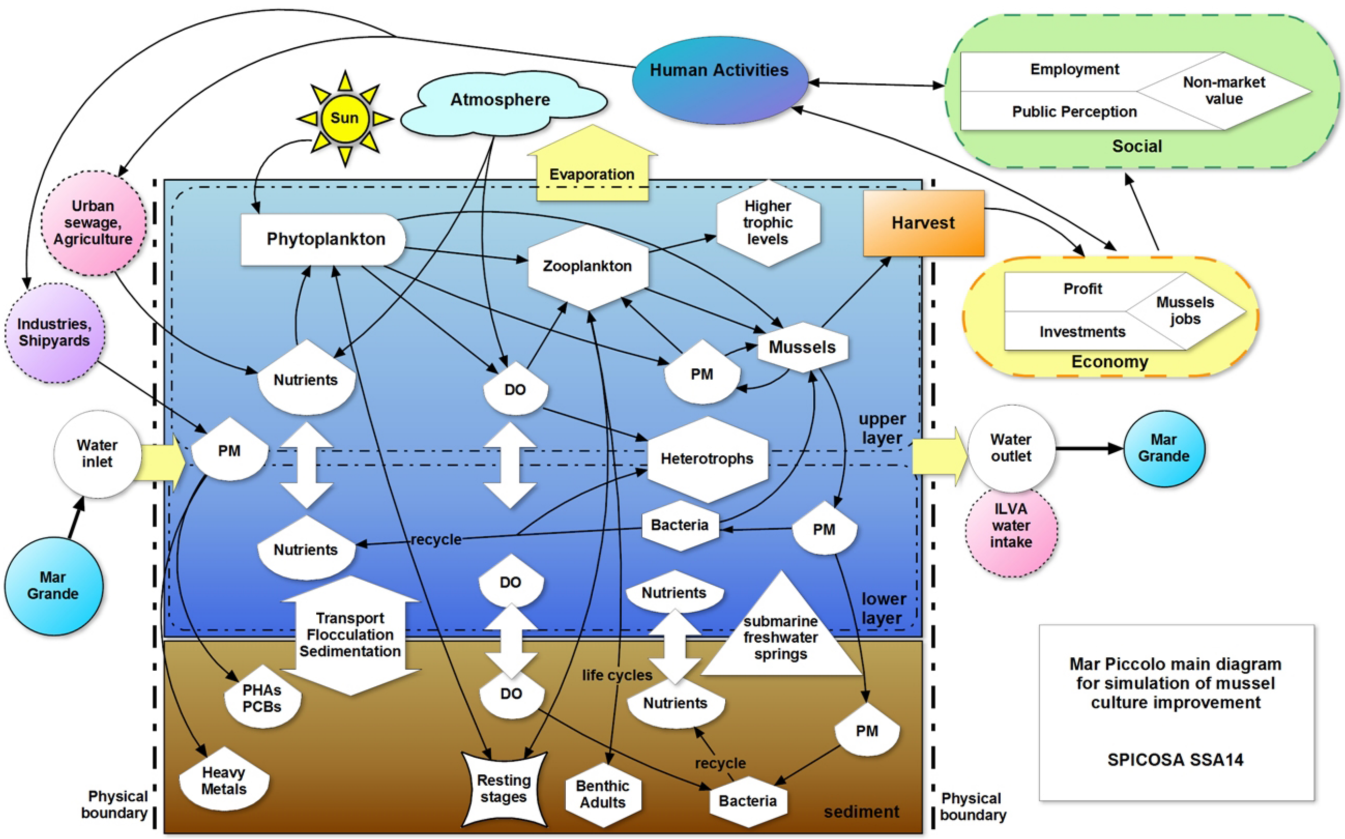
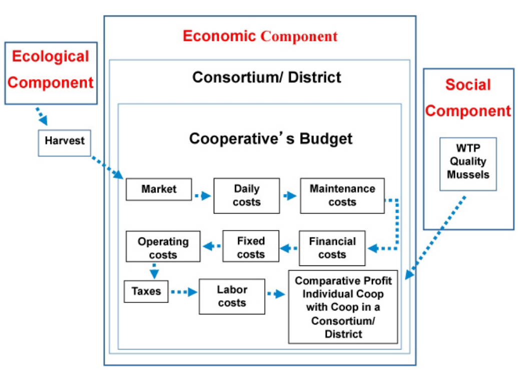


Fig. 4. Conceptual diagram of the socioeconomic component of the simulation model. The primary link between ecological and social-economical models is the mussel harvest. The secondary link between economical and social models is the willingness to pay (WTP) for quality mussels that influences the profits.

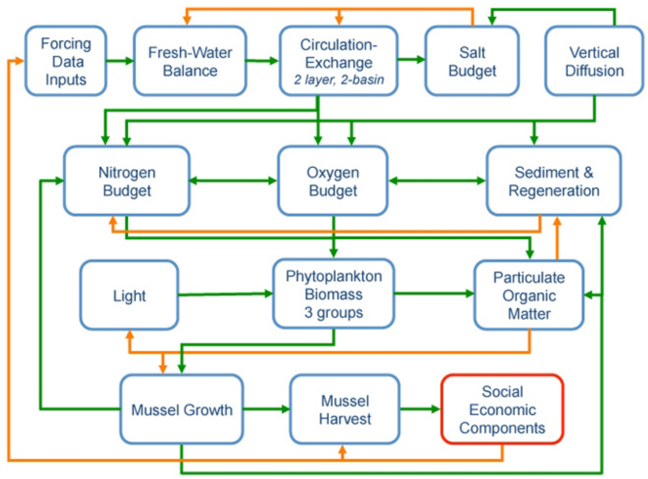


conservative and the dissolved nonconservative properties, such as oxygen and nitrogen. The nitrogen submodel includes nitrate and ammonia because they both influence phytoplankton productivity and species succession; ammonia excretion was input from mussel submodel. Phosphorus was not included in the current model version; the observed surface phosphate was often below the observational threshold. To understand their function in the bioproduction processes, the marine and terrestrial particulate organic carbon (POC) were simulated separately. These two components also originate from different sources: POC_{pp} from dead plankton and sinking losses, and POC_{dtr} from terrestrial sources with the freshwater runoff and with sewage discharges.

Phytoplankton

The primary production is doubly controlled, i.e., through top-down grazing by mussels and bottom-up by nutrient supply. These controls are further influenced by variability of internal and external processes, i.e., regenerating the nutrient supply because of weather patterns, regeneration, and excretion processes in mussel grazing and harvesting. Because our observations showed seasonal succession between three

Fig. 5. The main functional components of the simulation model based on the simulation software EXTEND™-Sim. The green lines are key interactions and the orange lines indicate strong feedback loops. Note that some variables such as phosphate, silicate, and zooplankton are not yet included in the model.



phytoplankton groups, we assumed that a representation of each of their biomasses would be necessary to simulate changes in the planktonic diet on the growth and quality of the mussels. We also separated the plankton growth functions into that because of the nitrate plus nitrite (“new”) deriving from sources external to the euphotic layer and that ammonia regenerated within the system and through mussel excretion.

The same set of equations was used to calculate the biomass growth and loss for each phytoplankton group except for group-dependent parameters (Table A.4). The growth rate for each group is calculated as the product of biomass concentration and the variable light and nutrient factors. The light factor in the upper layer is calculated from surface observations of solar radiation and a mean attenuation parameter (K_d), which agreed with the value derived from the mean Secchi disk depth using the empirical formula for transitional waters of Devlin et al. (2008). The growth factor is calculated using the Michaelis-Menten relation (Eppley and Peterson 1979, Moisan et al. 2005), in which the half-saturation values are specified from literature values and the calibrated value of Mu_max was held to within its published range. The loss-rate for each group is separated into two equations, one for the fixed losses proportional to the square of the phytoplankton concentration times the specified mortality, respiration, and zooplankton-grazing factors, and the second for the mussel grazing loss, which is dependent on phytoplankton and mussel concentrations (from Mussel submodel). The total phytoplankton biomass becomes a time-integrated balance between the growth and loss terms for the three groups.

The only existing data on phytoplankton composition and abundance were from 2003. However, surface chlorophyll *a* data were available from the sea-surface samplings of the 2002-2004 period, which allowed us to make a proxy estimate of the annual mean phytoplankton biomass (Table 3) by assuming a bulk ratio of 45 between chlorophyll *a* and carbon (Ribera d’Alcalà, *personal communication*). We used these annual means as calibration constraints for our simulation model of total biomass, production, and loss. As another control on the Phytoplankton submodel, the biomass of each group was calibrated to match the annual-mean of the percent composition, i.e., 68% diatoms, 17% dinoflagellates, 15% phytoflagellates. The mussel grazing was calibrated to optimize the carbon requirements for the mussel growth, while retaining the calibrated values for total plankton biomass and group percentages.

Mussels

The mussel submodel was calibrated to the annual mean biomass calculated from the top-down carbon calculation (Table 3). We then simulated the mussel growth by including the grazing flux of carbon from the phytoplankton submodel as (POC_{pp}), as well as that derived from detritus and mussels (POC_{dtr}) from the PysChem submodel. We included the POC_{dtr} in the model to obtain a better response to changes in food supply (phytoplankton groups and detritus) and to support future simulations of better wastewater treatment plants (WWTPs).

The mussel growth equation is based on the bioenergetic model of van Haren and Kooijman (1993) and its fundamental processes (Tables A.5-A.8). We assumed that filter-feeding mussels do not distinguish phytoplankton from detritus, but that the absorption efficiency *(AE)* differs (cf. Navarro et al. 1996). The control parameters on filtration rate and shell length were empirically formulated from the historical mussel biometric data (Pastore et al. 1976) and then used to calibrate the growth process. The effect of food availability and composition on mussel growth was simulated by comparing a year of optimal growth (1990) to a year (2003) of greater physiological stress in which the flesh weight was strongly reduced (Fig. 2c). We simulated the effects of different combinations of phytoplankton and detritus concentration (Fig. 6) on mussel growth (Bayne et al. 1989). Mussel growth efficiency was modeled by considering that the absorption efficiency (*AE*) depends on food composition and particularly on the presence of phytoplankton in the ingesta, moreover it can increase the *AE* of sedimentary organics (e.g., POC_{dtr}) in diets where detritus is the main component (Navarro et al. 1996). To represent the influence of diet variations on mussel

Table 3. Top-down calculations of mussel carbon budget for the mean expected harvest (ignoring seed stock) expressed as wet weight for two different trophic scenarios: years 1990, 2003. Values have been calculated by considering as a proxy the 1990 mussels physiological data, e.g., flesh dry weight % and carbon content. Globally, the carbon ingestion needed by mussels (F) is estimated as the sum of the carbon content of flesh dry weight (C, values from Brigolin et al. 2009), and the increase of carbon due to mean assimilation efficiency (D), both multiplied by the top-down trophic efficiency from mussels to phytoplankton (E, from Teramoto 1993, Townsend et al. 2000). In the lower part of the table the values of observed chlorophyll *a* converted to biomass (ratio Chl:C = 45) from year 2002 to year 2004 (simulation period) are reported to quantify the available biomass in each basin.

Mussel Carbon budget for year 1990 (CI = 15.5)				Total (10^3 kg)
A	Expected mussel harvest (wet weight)			30,000
B	Flesh dry weight of mussel harvest		7% of A	2100
C	Carbon content of flesh dry weight		40% of B	840
D	Increase of Carbon due to the averaged assimilation efficiency		25% of C	210
E	Increase of Carbon due to top-down trophic efficiency		(C+D)/0.2	5250
F	Total Carbon ingestion needed by mussels		= E	5250
*Values are calculated on MP basin area; a factor of 1/3 for SENO I and 2/3 for SENO II has been considered				
Mussel Carbon budget for year 2003 (CI = 9.5)				Total (10^3 kg)
A	Expected mussel harvest (wet weight)			50,000
B	Flesh dry weight of mussel harvest		4% of A	2000
C	Carbon content of flesh dry weight		40% of B	800
D	Increase of Carbon due to the averaged assimilation efficiency		25% of C	200
E	Increase of Carbon due to the averaged assimilation efficiency		(C+D)/0.2	5000
F	Total Carbon ingestion needed by mussels		= E	5000
*Values are calculated on MP Basin area; a factor of 1/3 for SENO I and 2/3 for SENO II has been considered				
Year	Units	MP	Seno I	Seno II
2002	Obs Chl *a* (µg l^{-1})	-	1.71	2.43
2003	Obs Chl *a* (µg l^{-1})	-	2.37	2.26
2004	Obs Chl *a* (µg l^{-1})	-	1.07	1.78
Annual means, daily values (µg l^{-1})			1.72	2.16
2002	Biomass (mg C m^{-3})	95.3	77.0	109.0
2003	Biomass (mg C m^{-3})	104.0	107.0	102.0
2004	Biomass (mg C m^{-3})	66.0	48.2	80.1
Annual means, daily values (mg C/m^3)		88.5	77.3	97.1
2002	Biomass (kg C d^{-1})	5700	2000	3700
2003	Biomass (kg C d^{-1})	6300	2800	3500
2004	Biomass (kg C d^{-1})	4000	1300	2700
Basin biomass, mean value (kg C d^{-1})		5300	2000	3300
Area, (m^2)		20,700,000	8,300,000	12,400,000
Volume (m^3, surface layer)		86,170,000	37,370,000	48,800,000

growth, we simulated three dietary scenarios that considered a mixture of detritus and phytoplankton groups (cf. Bayne et al. 1989, Roullion and Navarro 2003).

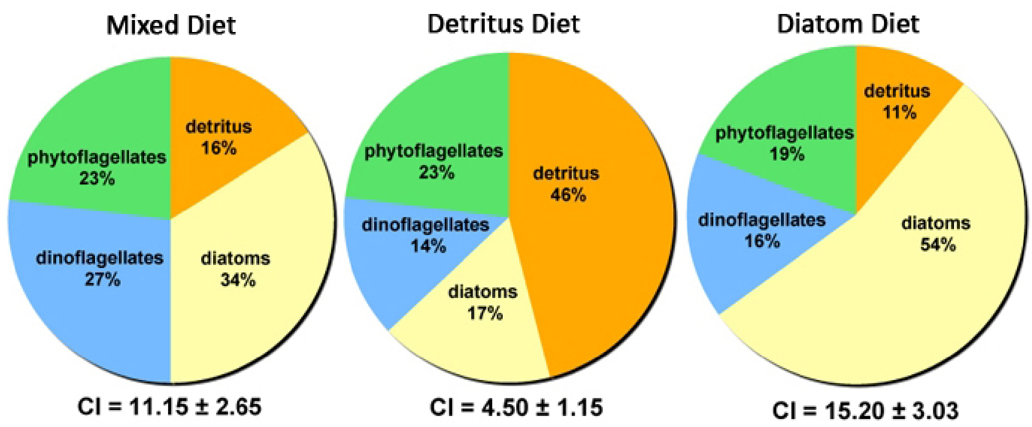
Mussel culture

Spatial distribution

The Mussel farm area covers half of Mar Piccolo (Fig. 1). An optimal farming distribution would be one in which the individual mussels would not be competing for food and allowing the total food biomass to sustain itself. Based on ecosystem trophic carbon budgets (Table 3), using the available biometric data, we estimated the carrying capacity for mussels of MP (Appendix 1, Tables A.5-A.8), by assuming that the total volume filtered per day should not exceed the incoming volume of new food, in terms of total POC constituted by phytoplankton and detritus, per day, considering the surface-layer flushing time of the basin and the volume occupied by mussels farms.

To demonstrate the sensitivity of mussel production to its spatial distribution, we simulated a “multiple-line” farm system with a nonintensive spatial distribution of mussel culture lines each with 5-m ropes hanging vertically with attached meshed socks containing the mussels (Fig. 7). Mussels are located in the euphotic layer and the depth was not a variable for mussel production. Each mussel cooperative covers an area of 9000 m² comprised of 6 sections of 1500 m². We simulated two different scenarios: intensive and nonintensive cultures, respectively, characterized by a line of socks separated horizontally by 2 m and vertically by 0.25 m,

Fig. 6. Mussel diet scenarios: composition of the three simulated diets by considering the main phytoplankton groups and detritus. For each scenario the CI was calculated and reported below the circles. Values are averages for three years of simulation (2002-2004).



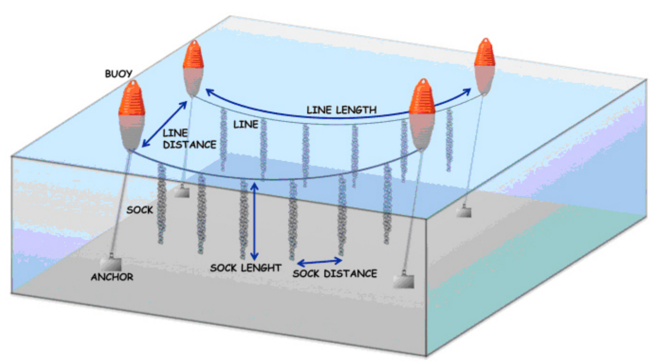
and another line separated horizontally by 4 m and vertically by 0.50 m. The 3-yr model simulation considered a representation of mussel farms having:

- Two mussel generations;
- Two spawning phases, from October to February each year;
- 150 days of harvesting time in the second and third year, ranging from May to October, during which harvest was parameterized as a constant loss term (a daily percentage of annual yields);
- A distribution of mussel seed stock of 1/3 in SENO I and 2/3 in the larger SENO II;
- An initial mussel seed stock equal to 1/7 of the desired annual production (~ 50,000 tons), as normally used by farmers.

Socioeconomic analyses

The socioeconomic component conducted three different analyses. A supply chain analysis was conducted in ExtendSim to simulate how the financial budgets of mussel cooperatives changed with variable harvests. A comparative analysis was then made to evaluate the differences in the profitability of the two management options, i.e., an individual cooperative and the cooperative belonging to a consortium, when subjected to variable environmental conditions that change the mussel quality (condition index, CI) and those that obstruct harvesting (hypoxic events; Table 4). We held all other variables equal, except for price, where we assumed a sale of 90% of harvest for the cooperative and 97% of the harvest for a cooperative in a consortium. The simulated mussel price depends on the condition index using three levels of CI with: > 18 high, 18 < medium > 15, and < 15 low.

Fig. 7. Design of a typical mussel farm in Taranto. The plan is arranged through the repetition of a basic unit, called "camera," made with stakes driven into the bottom. The camera is always a square, laterally bounded and diagonally crossed by "lines." Socks containing mussel nets are suspended from each line. This customary farming plan has recently been updated with polyethylene floats, known as "long lines," which are a modern variant of the traditional system. Both systems are currently used in Mar Piccolo.



- Mussel quality (CI): A cooperative in a consortium can negotiate higher prices than an individual cooperative regardless of the quality of the harvest. For the individual cooperative, we calculated the profit for each on the basis of three levels of mussel quality: high (CI = 20) 0.77 € kg^{-1}, medium (CI = 14.5) 0.50 € kg^{-1}, and low (CI = 7) 0.36 € kg^{-1}. Likewise for the consortium, we assigned the prices: high (CI = 20) 0.95 € kg^{-1}, medium (CI = 14.5) 0.60 € kg^{-1}, and low (CI = 7) 0.45 € kg^{-1}. This comparison

Table 4. Positive and negative aspects of an individual cooperative and a cooperative in a corsortium.

Individual cooperative		
	Positive Aspects	No Membership fees.
	Negative Aspects	Individual cooperatives cannot stop illegal mussel culture and sell less than a consortium/“distretto.”
		Expenses are higher than those of a cooperative in a consortium, where members share the costs.
Cooperative in a consortium		
	Positive Aspects	Higher productive integration.
		Lower production costs because of better management.
		Safeguarding of production and marketing process and protection of members against irregularities or abuse.
		Organization of markets to promote business with advertising.
		Production and services are promoted with quality trade marks.
		Higher sales because of the negotiation with external mussel markets of a better bulk price than that offered to an individual cooperative.
	Negative Aspects	Individual members pay a membership fee.

assumes homogenous mussel quality for each case calculated. To ensure homogeneous mussel quality, the farmers invert the socks such that the deeper parts are at the surface and vice versa to provide equal exposure.

- Hypoxic events: We assumed that hypoxic events reduced the harvest weight a further 10% and increased labor costs by 5% in transferring of the crop to Mar Grande. This operation incurs extra costs that are reflected in a lower selling price, i.e., for an individual cooperative and a cooperative in consortium the prices used were 0.36 € and 0.45 € kg^{-1}, respectively, regardless of the CI.

Third, we conducted a willingness to pay survey to determine the potential for public funding for improving the ecosystem health and thereby the quality of the mussels. We began with telephone interviews to determine the potential price for higher quality mussels similar to their historic level. Consumers were asked “How much are you willing to pay for one kg of mussels with a certification mark?” At the time of interviewing, the market base price was 0.77 € kg^{-1}, which indicates the wholesale price paid by restaurants or fishmongers, while the retail price to citizens was 1.00 € kg^{-1}. Because our use of traditional questionnaires was limited by lack of resources, we created a Facebook SPICOSA Group called “Friends of Mar Piccolo in Taranto” [Gli amici del Mar Piccolo di Taranto], as a mechanism to expand our survey and investigate the public perception of the Taranto mussels’ quality. In addition, we asked about the willingness to pay for an entry ticket to a green shoreline park area that featured small eateries and touristic events concerning the mussel farms.

Policy-stakeholders engagement

We had no prior experience with engaging nonscientists in our research, but as our approach and methods evolved so did their level of cooperation and interest. First, we encouraged politicians, stakeholders, and the public to participate in discussions based on their specific area of expertise. We held a total of nine meetings with our participant group to establish a sense of collaboration. These were organized at different locations, depending on the number of people invited for the occasion (Table 5). To start the process, we invited players involved in the management of the study site and individuals or groups belonging to the public, private organizations, and media. We also arranged private interviews, encounters, consultations, questionnaires, phone interviews, leaflets, and web operations, i.e., the Facebook group. In addition, we visited the mussel farms, where we took videos and spoke personally with the workers, all of which helped us understand their farming practices and some of their commonly encountered problems.

RESULTS

Operational ecosystem model

Physical-chemical

The PhysChem submodel simulates the main environmental conditions affecting primary production and mussel aquaculture. The estuarine exchange is quite responsive to the freshwater input causing relatively short flushing times, i.e., two to three weeks for Seno I and Seno II, respectively. The circulation controls the distribution of water properties through the processes of advection, entrainment, and diffusion, which were calibrated using observed mean salinities for each layer (Fig. 8a). Included in Fig. 8a are the freshwater inputs to the surface layer, which demonstrate the thermohaline dynamic, i.e., in response to a large pulse of freshwater, the upper layer salinity decreases and the estuarine outflow increases, and in compensation the bottom layer inflow increases and its salinity rises. The surface oxygen, which is controlled by the above physical processes plus photosynthesis and respiration, were in very good agreement with the observations. However, the agreement in lower layers (Fig. 8b) was equally good but failed to reproduce the observed hypoxia peaks because the model did not include the seasonal variation in the pycnocline depth and hence did not reflect the

Table 5. Synthesis of the stakeholder meetings.

Meeting date	Meeting Objective	Meeting Location	Stakeholders and number of Representatives	Participants
4.10.2007	Choose an "Impact"	IAMC-CNR Taranto	Municipality (2), Province (2), ARPA (2), ASL (1), Universities (1), Harbor Office (2), Harbor Authority (2), Media (5) Associations (1), Mussel farmers (2)	~ 25
17.10.2007	Choose a "policy issue" and present the ESE model	IAMC-CNR Taranto	Municipality (3), Province (3), ARPA (2), ASL (1), local Universities (2), Harbor Office (2), Harbor Authority (3), Industries (1), Associations (1), Mussel farmers (2), Media (5)	~ 30
30.05.2008	Choose the scenarios	IAMC-CNR Taranto	Municipality (1), Province (2), ARPA (1), ASL (1), Harbor Office (2) Armed Forces (2), Mussel farmers (2)	~ 15
11.02.2010	Discuss scenarios	Chamber of Commerce, Taranto	Municipality (3), Province (1), ARPA (1), ASL (1), Harbor Office (1), Harbor Authority (1), *Centro Ittico* (1), Chamber of Commerce (2), Mussel farmers (10), Media (5) Associations (1) University (1) Trade Unions (1)	~ 50
14.05.2010	Present the SAF to the academic community	Salento University, Lecce	PhD students (30), Lecce University representatives (5), Lecce Municipality (4), Lecce Province (4), Associations (5)	~ 70
23.07.2010	Organize the deliberation process	IAMC-CNR Taranto	Province (1), ARPA (1), Harbor Office (1),*Centro Ittico* (1), Mussel farmers (3)	~ 20
24.09.2010	Present results and outline deliberation process	Municipal Library, Taranto	Province (1), ARPA (1), ASL (1), Harbor Office (1), *Centro Ittico* (1), Mussel farmers (2), Media (5)	~ 30
07.02.2011	Present results and new perspectives	National Council of Research, Rome	Department of Earth and Environment (4), Ministry of Environment (2), other Institutes of Research (2), Istituto Superiore Sanità (2)	~ 20
07.04.2011	Present results and new perspectives	National Council of Research, Naples	IAMC-CNR personnel	~ 40

IAMC-CNR = Institute for Coastal Marine Environment - National Council of Research
ARPA = Regional Agency for Environmental Protection
ASL = Local Health Authority

reduced summer volume of the bottom layer, which thereby overestimates the oxygen available.

Simulation of the nitrogen and particulate organic budgets was made difficult because of the scarcity of data on inputs and on internal processes. The N-loading from land runoff needed to sustain the calibrations was ~ 130 tons y^{-1}. Sensitivity tests showed that reducing the N-loading did lower the surface-layer nitrogen proportionately, but it had little direct effect on the phytoplankton biomass because its input is a small proportion of the N stock in the system, which is maintained by other sources, i.e., from Mar Grande, regeneration, and atmospheric deposition. The role of ammonia is significant because of the active N regeneration and high mussel excretion. Fig. 8c shows the ammonia having a winter maximum and summer minimum, which is out of phase with the nitrate. The modeled variability in ammonia is in better agreement with surface observations than is the nitrate variability, but both are in good agreement with the annual means.

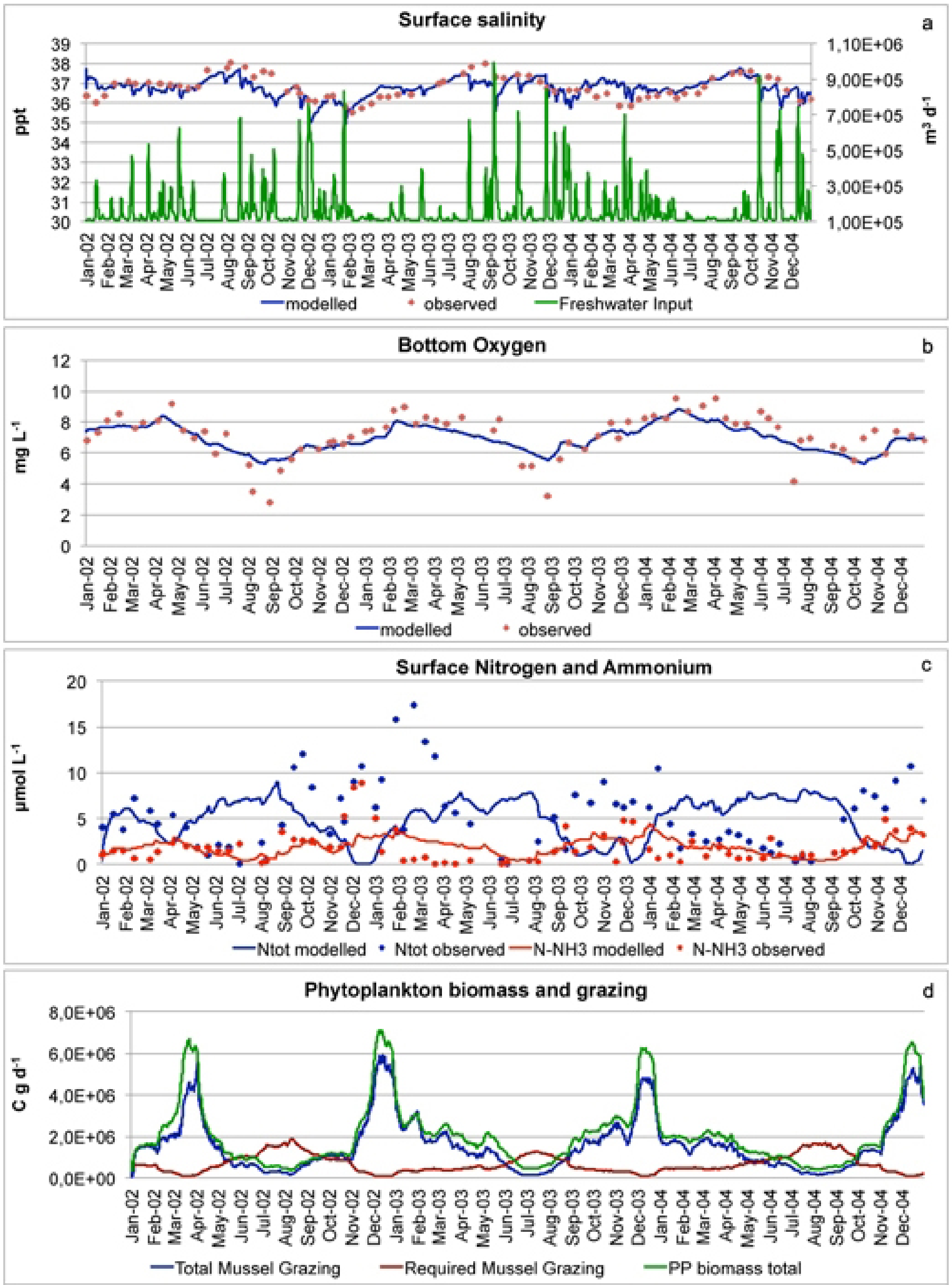
Phytoplankton

The phytoplankton submodel provided us with a better quantitative understanding of primary production and has raised some questions concerning the controls on its production. The phytoplankton biomass variability is out of phase with the mussel biomass in a manner that resembles a predator-prey relationship, i.e., plankton bloom when the mussel population (grazing) is at a minimum and vice versa (Figs. 8d, 9a). During winter, plankton growth is favored because grazing is low and new nitrogen is added from fall-winter runoff. During summer, the phytoplankton biomass minimum appears to be primarily caused by grazing, because of a minimum of diatoms, and limiting N/P ratios (phosphate is below detection levels in summer, G. Alabiso, *unpublished data*). During the July-August period the phytoplankton community composition changes, with an increase in phytoflagellates and a decrease in diatoms (Fig. 9b). Our interpretation is that mussels have less good food to sustain their weight during the summer harvest period. In sum, this complicated sequence suggests a strong control on the phytoplankton by the mussel grazing.

Mussels

The mussel model shows maximum biomass in August, before harvesting begins to reduce the population and a December minimum when the harvest is completed (Fig. 9a). Figure 8d

Fig. 8. Sub-basin Seno I: Examples of modeled surface and bottom layer variables relative to the vertically average values at one central station (red dots): (a) surface salinity, (b) bottom oxygen, (c) surface nitrogen (nitrite + nitrate) and ammonium, (d) phytoplankton biomass (green) and grazing as required by the mussel submodel (red) and mussel grazing as required by the PP submodel (blue).



indicates an interesting discrepancy from July to September when the mussel grazing calculated in the growth equation of the mussel submodel exceeds the total loss term in the plankton submodel. That is, there is not enough phytoplankton for the mussels. This suggests that the mussels must rely less on plankton and more on labile POC_{dtr} and/or loose flesh weight. This dynamic is confounded by the summer environmental conditions, which add a measure of stress or limit the mussel food supply. The limited historical evidence on the effects of diet comes from the recent changes in environmental conditions. Table 3 and Fig. 2c demonstrate the change from a good physiological status with a condition index of 15.5 (year 1990) to a stressed physiological status with a condition index of 9.5 (year 2003). The decrease in flesh argues for a reduced ratio of wet to dry weight from the healthy value of 7% to the unhealthy value of 4.0%. This in turn suggests that less phytoplankton carbon was available to support the mussels especially in a period like the summer that is per se physiologically stressing. At 4.0%, the amount of planktonic carbon is equal to that estimated (Table 3) needed to support the grazing requirement and would seem to be adequate on an annual basis. However, as mentioned above, it is the variability in the plankton biomass that makes it inadequate during the summer season.

The diet subcomponent of the Mussel model investigates the relevance of the mussel diet to growth. The simulation of the effects of three different diets on mussel growth, as demonstrated by condition index changes, showed that the optimal quality was attained when mussels fed on a purely diatom diet or a mixed diet. The mixed diet seems to be the most realistic, considering the dynamics of MP ecosystem. When compared to biometric datasets, this diet sensitivity helps us understand the increased stress on the mussels when deprived of their optimal diet (Fig. 9a,b), in particular that the contribution of detritus to the diets strongly influences absorption efficiency and consequently mussel growth, and quality.

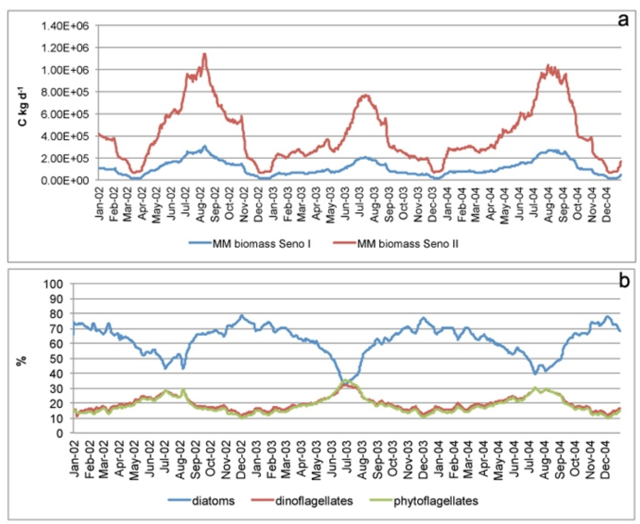
Spatial density of the farms is another factor affecting food supply. We simulated the growth difference related to two different spatial distributions (Fig. 10). The less dense distribution of lines gives a faster recovery after harvest or spawning-related stresses, and produces a higher mean biomass. These results demonstrate the potential for using simulation to optimize the timing of harvest and density of the lines. In addition, feedback from mussel farmers has indicated that using smaller diameter lines for larval attachment results in less competition for food and hence a higher production.

Mussel management

Our simulation analyses showed that the present individual mussel farms if organized into a consortium could realize higher income through higher prices, by minimizing losses due to natural events, and by utilizing better farming practices.

The economic comparison between revenues and costs of these two management structures operating under different environmental conditions is given in Table 6. The individual cooperative operates at an economic loss at all but the highest quality level and at a level harvest < 40,000 tons y^{-1}. In contrast, a cooperative in a consortium can profit from a harvest of only 30,000 tons y^{-1} if the CI is high, which effectively defines a base threshold condition for profitable aquaculture in Mar Piccolo. With the occurrence of hypoxia, both the individual cooperative and the cooperative in a consortium suffer losses independent of other conditions, because the remedial action is the same. Profits increase with higher CI (price) for both management schemes, but with a greater difference in favor of the cooperative in a consortium. Through continued dialogue with the farmers and responsible officials, concerning the additional benefits of reduced illegality, shared administrative expenses, and greater health benefits, we learned that the revelation of all these benefits contributed to the recent decision to reorganize the cooperatives into a consortium.

Fig. 9. (a) Simulated mussels biomass (MM) in sub-basins Seno I and Seno II; (b) Simulated phytoplankton composition as % of biomass for three groups of phytoplankton in Seno I.



Stakeholder/public involvement

The dialogue with city officials, regional environmental agencies, and stakeholders was mutually rewarding, despite some difficulties (Table 7). Sustainable development was a relatively new concept for the local authorities. However, repeated contact and discussions on general problems of mussel farming, and more specifically on the illegal exploitation of resources and the black market economy, showed that effective communication between scientists,

Table 6. Comparison of the profit realized between an individual cooperative and a cooperative in a consortium when exposed to different environmental conditions: those controlling the mussel quality (condition index) and those blocking production (hypoxic events). A negative value for profit represents a loss.

Scenarios	Individual cooperative (sells 90% of harvest)		Cooperative in a consortium (sells 97% of harvest)	
	Average profit (x € 1,000)		Average profit (x € 1,000)	
	Without hypoxia	Hypoxia (0.36 € kg^{-1})	Without hypoxia	Hypoxia (0.45 € kg^{-1})
HARVEST: 30,000 tons y^{-1} Market price:				
CI: 7.0 (Low) *coop* 0.36 € kg^{-1} *consortium*: 0.45 € kg^{-1}	-428,00	-443,00	-145,00	-156,00
CI: 14.5 (Medium) *coop* 0.50 € kg^{-1} *consortium*: 0.60 € kg^{-1}	-306,00	-443,00	-4,00	-156,00
CI: 20.0 (High) *coop*. 0.77 € kg^{-1} *consortium*: 0.95 € kg^{-1}	-71,00	-443,00	325,00	-156,00
HARVEST: 40,000 tons y^{-1} Market price:				
CI: 7.0 (Low) *coop* 0.36 € kg^{-1} *consortium*: 0.45 € kg^{-1}	-324,00	-338,00	-4,00	-15,00
CI: 14.5 (Medium) *coop* 0.50 € kg^{-1} *consortium*: 0.60 € kg^{-1}	-161,00	-338,00	184,00	-15,00
CI: 20.0 (High) *coop*. 0.77 € kg^{-1} *consortium*: 0.95 € kg^{-1}	153,00	-338,00	622,00	-15,00
HARVEST: 50,000 tons y^{-1} Market price:				
CI: 7.0 (Low) *coop* 0.36 € kg^{-1} *consortium*: 0.45 € kg^{-1}	-219,00	-234,00	137,00	126,00
CI: 14.5 (Medium) *coop* 0.50 € kg^{-1} *consortium*: 0.60 € kg^{-1}	-16,00	-234,00	372,00	126,00
CI: 20.0 (High) *coop*. 0.77 € kg^{-1} *consortium*: 0.95 € kg^{-1}	376,00	-234,00	919,00	126,00

public officials, and businessmen could contribute to sustainable management of local resources. The participating stakeholders increasingly provided information that was not officially available yet crucial for constructing the simulation model, e.g., the harvest levels, problems with permits resulting in illegal farming, and waste discharge management. This exchange was valuable for us researchers, by providing not only new knowledge, but also new ideas on how sustainable development might actually be initiated and implemented. Thus, these interactions increased the collaborative effectiveness because the different groups became more familiar with their shared interests. This was judged subjectively by their willingness to attend meetings and interact more with others and with us.

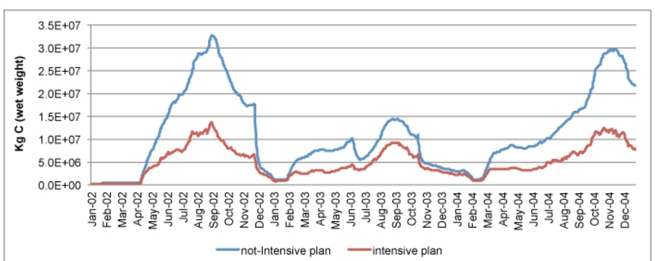
Facebook allowed us to communicate quickly and efficiently with large numbers of people. The Facebook page has been particularly helpful, with videos explaining the meaning and objectives of the project and describing the MP mussel culture. At the time of writing, 182 members had demonstrated a good level of activity, and 86 members had responded to questions on public perception of the Taranto mussels through the

Table 7. Stakeholder involvement and some opinions.

Regional Agency for Environmental Protection (ARPA)	Representatives actively participated in all meetings since the very beginning and contributed information helpful to the development of the model. "*I'm eager to see final results because this project contains all the components that are often treated separately...I appreciate how this team is approaching all aspects and hope they can merge all the policy components.*"
Taranto Province	Representatives were always in good attendance and demonstrated strong interest to cooperate, even though different individuals attended different meetings. Post-project interest remains strong, particularly with regard to the sewage treatment solutions and to the continued use of the model. "*The project is very useful for institutions...it needs to revise the model also with technicians present in province...it has done very complete work and we look forward to seeing the final model with more details.*"
Taranto Municipality	Representatives always attended and were interested and cooperative.
Harbor Office	Representatives contributed their know-how and continued to collaborate even after a change in personnel. *"a model such as that created by SPICOSA is desperately needed and should be used by the institutions to implement a genuine land-use planning...The MP should be divided into plots of production (lots) on the basis of technical parameters established by the SPICOSA model to improve productivity and quality of mussels. The results of this work will be incorporated into the strategies of the distretto to improve production with obvious repercussions for social and economic issues. This could also be useful to reduce the high concentration of facilities in MP."*
Municipality – "Centro Ittico"	The director has expressed special interest in using the model to support the planning and management of Mar Piccolo and regulate state concessions.
Local Health Authority (ASL)	Representatives actively participated in all meetings since the very beginning and contributed information helpful to the development of the model. "*...it is extremely important that Taranto mussels be healthy and of high quality...Farmers may then understand that that they could cut the production effort by half and triple the price.*"
University/Academic	Professors were present and interested in the project, which was also presented to PhD students of the University of Lecce.
Media	Always present at our meetings, devoted to the project, and dedicated generous slots in newspapers and TV news.
Harbor Authority	Attended only the initial meetings, because they are not direct users of the Mar Piccolo.
Industries	Attended only the initial meetings.
Mussel farmers Cooperatives	After the first initial encounters, the farmers participated actively in meetings and cooperated by providing information otherwise not available from official sources. Our work was assisted by the intervention of a facilitator, who is very familiar with farmers' issues.

SPICOSA = Science and Policy Integration for Coastal System Assessment

Fig. 10. Total mussel carbon content simulated for intensive (socks 0.25 m apart, lines 2 m apart) and less intensive (socks 0.5m, lines 4 m apart) mussel farms in sub-basins Seno I and Seno II in 2002-2004.



willingness to pay method. Although phone interviews indicated an average willingness to pay 1.50 € kg^{-1} (45% of interviewees), the Facebook response was much higher: 2.50 - 3.00 € kg^{-1} (80% of interviewees). This might be explained by the generational difference of the younger Facebook users who are often more attentive to the media and perhaps to quality and provenance of food. These results were particularly useful for establishing the nonmarket values for the economic simulation and for evaluating the public awareness for environmental sustainability issues and its support for developing shoreline recreational facilities. Our use of Facebook showed its value as an interactive communication tool for user engagement and information exchange (cf. Lorenzetti 2010).

DISCUSSION

An obvious benefit of the SAF application is the flexibility of the simulation analysis that allowed us to begin to understand the complex factors controlling mussel production in the context of Mar Piccolo's carrying capacity. Our results helped to incorporate the socioeconomic needs into a more integrated plan for sustainable development in the Taranto Region. To demonstrate this we focused on three elements, a simulation model as an information tool, management options for more sustainable mussel culture, and the perspectives of public support for sustainable development. Although none of these were truly completed, they were sufficient to demonstrate their potential value. A very significant value of our SAF exercise was that it opened up new potentials in research, aquaculture organization, and collaborative planning of a common resource and provided a sound basis for their continuance.

Operational ecosystems model

The ecosystems model had the objective of representing the ecosystem's response, i.e., from rain to revenue. This was achieved for the conservative parameters of freshwater, salinity, interbasin exchange, and diffusion, but was less successful for processes that are influenced by biology, because of lack of data to validate the complex interactions within the system, i.e., for nitrogen and particulate organic matter. The model provided a preliminary answer to our policy issue, i.e., that the phytoplankton production is not sufficient to support the mussels through the summer harvest mostly due to overgrazing, lack of labile detritus, and a nonoptimal plankton composition. This last aspect is complicated by the superimposition of sewage inlets reduction from 1990 to 2003, which in the past were the most abundant sources of labile detritus.

To take this conclusion to a more definite level, we would need better observational data for the key processes and inputs. The implications for improving the discharges to optimize plankton growth and composition could also be addressed by an improved model.

Even at this stage, the model is extremely useful for planning systematic observational programs, for following the response to environmental events, e.g., droughts, heavy rains, blooms, hypoxia, for pursuing process research, i.e., primary production, mussel growth role of community structure, role of nutrients and detritus, and for collaborating with mussel farmers, i.e., timing of harvest, dealing with hypoxia, density of lines, improving mussel quality, estimating carrying capacity.

Guide for mussel management

Our SAF application provided a mechanism to explain and discuss the problems of managing and sustaining an economically viable mussel culture. The mussel farmers easily perceived the advantage of simulating various technical practices as opposed to a trial and error approach. Such 'testing' is currently in practice as the farmers attempt to change their techniques to adapt to changes in inputs making them very receptive to further collaboration. City authorities and mussel farmers appreciated the advantages of converting to a consortium/"distretto" and the concept of using the modeled carrying capacity as a guide for harvest. They demonstrated a willingness to collaborate with each other to improve incomes and to assist in promoting the sustainability of the MP. Coincidentally, soon after the project, the authorities from the "Centro Ittico Tarantino" together with provincial and regional representatives approved reorganization to a distretto of mussel culture (Department of Economic Development of the Apulia Region 2011).

Collaboration and public participation

The SAF application focused on constructing a collaborative partnership with the stakeholders and the public. Although this could be pursued only to a limited degree and is a gradual process, we made important first steps toward this goal. Our relation with the mussel farmers started with hesitation and skepticism and ended with a healthy enthusiasm. Similarly with the city and regional authorities, we experienced a gradual improvement in willingness to collaborate and plan for continued use of the SAF. By the end of the application, the people of the Apulia Region were discussing with us ways to utilize the SAF for environmental management problems. The effort to communicate and encourage public participation in creating a more sustainable city was favorably demonstrated through the Facebook page. The level of interest was entirely unanticipated as enthusiastic discussions ensued on feasible options, such as the promotion of a quality mark for mussels, boosting tourism through catering services and hospitality sectors, and through tours of the farms and a museum of the history of Taranto mussel culture.

CONCLUSIONS

We feel that our application of the SAF has opened a new arena for research and collaboration with local authorities and the public. Clearly, our simulation analysis and its model are not complete; only some of our implied actions have been taken and public opinion and perception has not yet changed to an effective level. What has changed is the feeling of optimism about the feasibility of science-policy collaboration for sustainable development. In sum, our exercise, if continued, could result in better-integrated solutions regarding sustainable development.

The SAF application provided a learning platform for asking detailed questions within a structure simulation analysis. Because this process is contagious, we found that the participating stakeholders began to ask questions and have more confidence in facing their problems. Our list of specific lessons learned is too long; here we give a few of which we hope will interest the reader.

1. The systems approach requires different data sets than those used in descriptive or mono-disciplinary research, particularly concerning, e.g., inputs, internal processes, feedback loops, resource use and perception, economic data on related human activities. The cooperative experience of planning a simulation was a powerful, multidisciplinary learning tool.

2. The model is a valuable tool for following the productivity of mussel culture and to experiment with different operating strategies. Politicians could use this

tool for evaluating the effects of their decisions on sustainable use of the coastal resources, particularly concerning spatial planning for aquaculture in MP.

3. We learned that a participatory relationship with the stakeholders matured to a much more collaborative nature. They appreciated sharing the SAF process and the opportunity for open dialogues on an equal basis with other stakeholders. They particularly appreciated our use of conceptual diagrams and of new possibilities to make operational changes coupled with better management and collaboration with local authorities.
4. The public is surprisingly eager for sustainable solutions. The Taranto public demonstrated a good level of perception and a strong belief in the potential of Taranto mussels to become sustainable and once again the proud symbol of local tradition and culture. On the other hand, soliciting participation from large industry or high decision makers is deemed more difficult.
5. As researchers, we learned a lot about the function of the Mar Piccolo system and how best to monitor it for improved simulations. The model has raised questions that need further investigation, such as clarifying the roles that N-loading, N-regeneration, detritus, phytoplankton species play in creating an improved food supply for the mussel culture, and vice versa, how the mussel culture influences its own food supply.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol17/iss3/art10/responses/

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Appendix 1. This Appendix explains and describes the functional content of the Mar Piccolo model. Approximations are to meet 1st order simulation with insufficient data. All processes/variables are used in each of the basins (Seno I & II), and most in both layers.

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