Appendix G   Primary production and fisheries in Lingayen Gulf, northern Philippines: biological oceanography component

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Introduction

One of the goals of the SARCS/WOTRO/LOICZ project is to understand the biogeochemical processes that occur in the coastal zone of the South East Asian Region. Among the major processes of interest is the cycling of carbon as a biogenic material. This paper looks at the production of carbon in Lingayen Gulf, northern Philippines and how this interacts with the harvest of carbon in the form of fish biomass. It aims to provide estimates of carbon production by various producers and using these, determine the extent of fisheries exploitation in Lingayen Gulf. It also examines the interactions between primary production and the trophic composition of the catch.

Until recently, fisheries management has often been based on single species models of exploited stocks, originally developed for the high latitude marine ecosystems (Pauly 1979). Unfortunately, the kinds of data needed for these models (e.g., age at catch) are frequently unavailable in less industrialized countries. More important is the fact that much more species are exploited in tropical areas, for example 341 species from trawls in eastern peninsular Malaysia, 173 from the Visayas Seas in the Philippines (various references in Pauly 1979), and thus interactions among various species and stocks complicate any analysis. The realization that fisheries cannot be considered or assessed properly in isolation of its support systems, as had been the norm in the past as fisheries biology, oceanography, and ecology have gone in their own ways (Larkin 1996), has led to the development of even more complicated multi-species models and simulations (see Larkin and Gazey 1982). These trends have meant developing countries face greater challenges in understanding the dynamics of their fishery in the face of the demands of their rapidly increasing population.

A promising approach in assessing condition of multi-species fisheries (via assessment of primary production required to support the system) is the use trophic balance models such as those implemented in ECOPATH models (Christensen and Pauly 1992). Such approaches divide the system into a series of functional or species groups with similar diets, production, and consumption patterns; and seek to balance the energy / nutrient budgets under an equilibrium assumption. Thus, steady-state biomasses of each of the living groups in the system could be computed, which could then be the basis for estimates of carrying capacity, and sustainable yield. Although designed mainly for biotic/living components of the system, nutrient levels and other physical factors could be included indirectly through their effect on productivity levels. The applicability of this approach is explored in this work.

Methods

Carbon production. Primary production estimates for Lingayen Gulf were obtained using empirical data on chlorophyll $\underline{a}$ and bacterioplankton growth rates while coral and macrophyte production were derived from secondary literature. Data on chlorophyll $\underline{a}$ were obtained from four cruises conducted in Lingayen Gulf in February and April 1997, April 1998 and July 1999. For the first three cruises, samples for chlorophyll $\underline{a}$ analysis were filtered unto GFC glass fiber filters, frozen and later analyzed using a spectrophotometer following the method given by Parsons et al. (1984). In the last cruise, chlorophyll $\underline{a}$ was estimated using a fluorescence sensor inside a Nu-shuttle housing as well as by the spectrophotometric method. Nu-shuttle values were approx. 40% that estimated by spectrophotometry.

Estimates for chlorophyll $\underline{a}$ were converted to production using a sinusoidally fitted light regime for a twelve hour day, an I_{sat} of 150 uE m^{-2} s^{-1} (McManus et al., manuscript) and a P_{max} (tropical and nitrogen poor waters) of 3.15 mg C Chl a^{-1} hr^{-1} (Parsons et al, 1984).

Production estimates using the light and dark bottle method were obtained in waters with and without fishpens, to get values along a eutrophication gradient. Water samples were incubated *in situ*, and were fixed after a 4-hour incubation and analyzed following the modified Winkler method using an auto-titrator (Parsons et al., 1984; 751 GPD Titrino, Metrohm).

For bacterial production, water samples for bacterial counts and growth rates were collected from below surface (1 meter), at mid depth, and near bottom, using a Niskin sampler. A sample volume of 15-20 ml was taken and preserved to 1% glutaraldehyde final concentration. To determine growth rates, samples were incubated *in situ* by suspending the bottles at different depths (1, 5 and 10 m) and a subsample of 40 ml was taken at the start of incubation and every three hours thereafter for 24 hours (Agawin et al., unpublished). The samples were later filtered through a 0.20 um black Nucleopore filter under 1-2 cm Hg pressure, and stained with DAPI solution. These were mounted in a glass slide with a drop of Zeiss immersion oil and examined under an epiflourescence microscope. Both hetero- and autotrophic bacteria fluoresce bluish white under UV excitation. Counts for autotrophic bacteria which fluoresce yellow under blue light excitation were provided by Agawin (pers. comm.). The latter were subtracted from the total counts to obtain numbers for heterotrophic bacteria. Daily growth rates and mean cell densities together with values of cellular carbon content (0.123 pg C μm^{-3}; Waterbury et al.) and cell volume of 0.63 $\mu m3$ (Agawin et al., unpublished) were used to obtain estimates of bacterial production. Estimates for coral and macrophytes growth rates were derived from secondary literature and converted into carbon production following Westlake (1963).

Primary production required. The primary production required (PPR) was estimated using two methods. The first was computed by ECOPATH 3.0 (see www.ecopath.org) by deriving steady state biomasses for each fish group and computing the needed phytoplankton production to support these. The catch statistics were summarized into ten groups (herbivorous fishes, miscellaneous demersals, leiognathids, crustaceans, small pelagics, intermediate predators, scombrids, barracuda, *Loligo* spp., phytoplankton, zooplankton, zoobenthos, and juvenile fish) modified from those used by Guarin's (1991) model of Lingayen Gulf. Summaries were constructed for every year from 1978 to 1987. Data for succeeding periods are available but were not used since there were a change in the agency conducting the monitoring, the area covered, and the types of fish groups recorded. Corresponding diet compositions, production/ biomass ratios, (and ecotrophic efficiencies), as well as biomass estimates for those groups for which no data were available (phytoplankton, zooplankton, zoobenthos, juvenile fish) were likewise taken from Guarin (1991) but updated using summaries in Fishbase 97. From the above data, ECOPATH estimated the "best" balanced combination of biomasses. Net PPR required was then computed as the product of the estimated phytoplankton biomass (the only primary producer in the model), the production/biomass ratio, and the ecotrophic efficiency (i.e., the proportion of the energy input into the phytoplankton group that is exported).

The second method used to estimate PPR relied on the basic equation of Pauly and Christensen (1995), which incorporated the parameters for weighted mean trophic level and biomass of the harvested groups. As in the ECOPATH analyses, catch data in Lingayen Gulf for the period 1978-1987 were used. A conversion factor of 9 for wet weight to dry weight ratio was used in the first (ECOPATH) analyses. Ratios of 0.14 fish wet weight to dry weight and 0.38 fish dry weight to carbon (Parsons et al., 1984) were used in the second analyses.

Results

Carbon Production. Production of carbon in Lingayen Gulf by various components is presented in Table G1. Phytoplankton accounted for 29%, bacterioplankton, 42%; while corals and macrophytes contributed 29%. Of that produced by bacterioplankton, heterotrophic bacteria accounted for 99% while autotrophic bacteria contributed only 1%. This validates the heterotrophic condition of the upper Gulf as indicated in the biogeochemical budgets done for the Gulf (McGlone et al. 1999).

Table G1. System carbon production by component in Lingayen Gulf.

Primary producer	Production (t C km^{-2} yr^{-1})	Area (km^2)	Areal production (t C yr^{-1})	Percent contribution (%)
Phytoplankton (McManus et al., this study)				
• Open Gulf	93.5	1,900	177,678.5	
• Bolinao	166.8	200	33,350.0	
Sub-total	100.5	2,100	211,028.5	29
Bacterioplankton (McManus et al., this study; Agawin et al., manuscript)				
• Heterotrophic Bacteria	146.0	2,100	306,684.0	
• Autotrophic Bacteria	1.7	2,100	3612.0	
Sub-total	147.8	2,100	310,296.0	42
Benthic producers				
• Seagrasses (Fortes, 1990)	511.0	60	30,660.0	
• Seaweeds (Westlake,1963)	118.00	14	1,652.0	
• Corals (Westlake, 1963				
• Reef flat	4,120.0	10 (MGB-DENR & Nikko 1995; McManus, pers.comm)	41,612.0	
• Reef slope	4,120.0	34.8 (MGB-DENR & Nikko , 1995; McManus, pers.comm)	143,376.0	
• Subtotal	103.5	2,100.0	217,300.0	29
Total Primary Production	351.8	2,100.0	738,624.5	100

The empirically derived phytoplankton production was compared to that estimated using nutrient budgets which were based on the Redfield elemental ratio for phytoplankton (McGlone et al. 1999) (Table G2). Between these two estimates, an average of 86.2 t C km^{-2} yr^{-1} net phytoplankton production was obtained.

The amount of fish catch was converted to equivalent phytoplankton production using two methods as indicated in Table G2. The mean estimate of harvested biomass in terms of phytoplankton was 57.6 t C km^{-2} yr^{-1}.

Table G2. Net phytoplankton production and fisheries harvest in Lingayen Gulf.

Parameter	Value
1. Net phytoplankton production in Lingayen Gulf (McManus et al, this study)	100.5 t C km^{-2} yr^{-1}
2. Net phytoplankton production = (p-r) =+ 6 mol m^{-2} yr^{-1} (McGlone et al., this study)	72.0 t C km^{-2} yr^{-1}
3. Average of Estimates (1) and (2)	86.2 t C km^{-2} yr^{-1}
4. Mean harvested fish biomass in equivalent phytoplankton production required estimated by ECOPATH (9:1 wet weight to dry weight ratio)	40.0 t C km^{-2} yr^{-1}
5. Mean harvested fish biomass in equivalent phytoplankton production required estimated by fish carbon and weighted trophic level for 1978-1987 catch data (Pauly and Christensen 1995; Parsons et al,1984 and McManus et al., this study)	75.2 t C km^{-2} yr^{-1}
6. Average of Estimates (4) and (5)	57.6 t C km^{-2} yr^{-1}
7. Index of exploitation = Mean harvested phytoplankton production / Mean net Phytoplankton production; 8. Optimal exploitation = 0.50 (Modified after Gulland, 1971)	0.67

A comparison of the per year PPR computations relative to the catch is shown in Figure 17 (main report). Computed PPR (averaging around 360 mt wet weight /km²/year) essentially followed the trend in catch over the ten year period, with total catch increasing 90% and PPR increasing 95%. Total biomass estimated by ECOPATH only increased 32% over the same period showing increased fishing pressure (which is mainly on the higher trophic levels) and consequent increases in PPR.

There was an overall increase in the catch of all groups in the ten-year period from 1978 to 1987 (Figures 18 and 19, main report). Those with steepest slopes of the regression line were miscellaneous demersals and scombrids while barracuda had the least.   Note though that barracuda, crustaceans, and herbivorous fishes actually had slight decreases in the first five years (1978 to 1982) while scombrids had marked decreases in the succeeding five years (1983 to 1987).

The simultaneous initial decline of both barracuda and herbivorous fishes (in contrast to one increasing while the other decreases) is not unexpected since barracuda has a greater trophic impact on the intermediate predators (of herbivorous fish). Hence a decrease in barracuda because of fishing could benefit the predators of herbivorous fish.

Discussion

The ratio of harvested biomass to net phytoplankton production was used to determine the level of exploitation rate (see Table G2). At 67% exploitation rate, the Lingayen Gulf can be considered overexploited using catch data for the period 1978-1987. As a consequence, there seems to be some shifts in the trophic levels of the groups harvested, i.e., fishing may be closer to the base of the trophic pyramid and thus more and more omnivores and herbivores are being caught as the predators are depleted. Proportional catch of groups higher in the food web such as of small pelagics and intermediate predators declined (Figure 18 main report), as did the scombrids after a period of increase. Catch of groups lower in the food web (as a proportion of total catch; Figure 19, main report) increased as is the case with leiognathids, miscellaneous demersals, and herbivorous fishes. However, factors such as influence of market demand and changes in gear composition and effort cautions against detailed interpretation of catch data in terms of trophic levels. For one, the decline in scombrids does not seem related to such trophic cascades. ECOPATH shows fishing mortality in scombrids is only half of total mortality, which at face value does not suggest overfishing. However, fishing mortality for predators such as *Loligo* (mean trophic level of 3.5) small pelagics (trophic level of 3.6), intermediate predators (trophic level of 3.8), and barracuda

(trophic level of 4.4) range from 70 to 95% of total mortality in 1987. This indicates severe overfishing of these predator stocks if the Lingayen Gulf system is assumed closed. However, it is more likely that fishing boats going after these stocks fish farther out in the South China Sea, and that Lingayen Gulf is actually supporting a smaller biomass of these predators. One can then argue that 67% exploitation rate may be limited by the fact that the phytoplankton used to support the fisheries is not just those found within the Gulf. For small and big pelagics, the feeding grounds can include areas within their migration routes, e.g. portions of the South China Sea. Thus, it is not sufficient to establish a state of overfishing purely on the basis of trophic dynamics. In the case of Lingayen Gulf however, Silvestre et al. (1991) also concluded that the fisheries showed biological overfishing with a high yield to biomass ratio of 5.2 using empirical data from 1987 to 1988.

Trophic cascades have been described for a number of marine systems involving fisheries, pollution, eutrophication, and species introductions (Larkin 1996). The Gulf of Thailand situation has often been used to illustrate shifts in dominance due to stock interactions as a result of fishing (Gulland 1976 in Pauly 1979). Here, catches of rays have decreased as those of squids (and now, "trash fish") increased. Note though that contrary to expectations, small, short-lived prey species in the Gulf of Thailand have been shown to decrease faster than their predators because of the combined effects of fishery and predatory mortality (Pauly 1979).

The present analysis suggests that there may be trophic interactions involved in the changes in the relative compositions of the catch. However, interactions other than trophic ones may also be involved. A possibility is fishing selection driven by market demand, and strong differences in system boundaries of the modeled groups. Hence, primary data collection, and not just analysis of secondary data is required. There is a need for further disaggregation of the species groups as the data allows. Individual species may stand to benefit from disaggregation to size or age classes in recognition of ontogenetic shifts in diet, consumption, and mortality patterns. Differences in ranges of the species (e.g., pelagic fishes versus demersal fishes) also must be considered, something that can be addressed in the ECOSPACE module also being tested in the Alpha version of ECOPATH used in this analysis.

ECOPATH models have the advantage of requiring relatively little input compared to other models available for fisheries assessment and modeling. However, it only gives a static picture of the trophic structure of the ecosystem modeled, showing the levels of trophic flow needed to this current structure given observed growth and mortality patterns (Walters et al., 1997). The addition of the ECOSIM module to ECOPATH allowed for more dynamic simulations needed in examining various scenarios such as of changes in fishing patterns or policies (see Walters et al. 1997) in a multi-species setting that is more realistic for tropical situations. This module requires little additional data above the inputs to ECOPATH to perform temporal analyses. Although ECOPATH and ECOSIM are still data intensive, parameter inputs are becoming more widely available (see Christensen and Pauly 1992, 1993; and Fishbase: Froese and Pauly 1997). Numbers adopted for similar systems and situations could be used as initial inputs and the preliminary models derived from them could then serve to help prioritize which inputs require refinement and additional data collection.

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