An Ecosystem Model of San Pedro Bay, Leyte, Philippines: Initial Parameter Estimates

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Abstract

A mass-balance model of the trophic structure of San Pedro Bay, Leyte Province, Philippines was constructed using the Ecopath modeling software. The model is composed of 16 ecological groups (13 consumer, 2 producers, 1 detritus groups). The input parameters were obtained from the resource assessments studies conducted in 1994 - 95 and the biomass of Leiognathidae, an important group of small demersal fishes was estimated from trawl survey data using the swept-area method. The model indicated that the average trophic level of the fishery catches is 3.25.

Introduction

San Pedro Bay is located in the central Philippines (Fig. 1), with coordinates 125º 00' to 125º 14' N latitude and 11º 05' 30" to 11º 17' 30" E longitude. The bay is bounded on the west by the island of Leyte and on the east by the island of Samar. It has an average depth of about 20 m, with a maximum recorded depth of 36.6 m and an area of approximately 625 km^2 (Armada 1996). The bottom consists primarily of sandy/muddy substrate, with reefs and seagrass beds distributed along much of the coast.

Ecosystem models using the Ecopath software have been presented from several coastal areas in the Philippines, notably Lingayen Gulf (Guarin 1991), San Miguel Bay (Bundy and Pauly 2001; Palomares et al. 1994), Lagonoy Gulf (Garces et al. 1995), Soarsogon Bay (Cinco 1995), and the Bolinao reef ecosystem (Aliño et al. 1993). This paper aims to contribute to this valuable database by analyzing the fisheries resources of San Pedro Bay using the Ecopath with Ecosim software. Various sources of information, particularly the results of the resource assessments in San Pedro Bay in 1994 - 95 were available for this (Armada 1996; Babaran et al. 1997; Batang 1996; Villoso 1996).

Materials and Methods

Modeling Approach

The ecosystem model of San Pedro Bay, Philippines was constructed using the Ecopath with Ecosim (EwE) software following the approach described in (Christensen et al. 2000). Ecopath is a trophic modeling approach that has been used to model a wide variety of aquatic ecosystems (Christensen and Pauly 1993). The method is also used to analyze trophic interactions and state variables (biomasses) derived from quantitative steady state models of aquatic systems (Christensen and Pauly 1992a; Christensen and Pauly 1992b).

Ecopath combines an approach by (Polovina 1984) for estimation of biomass and food consumption of the various elements (species or groups of species) of an aquatic ecosystem with that of (Ulanowicz 1986) for analysis of flows between the elements of ecosystems. The approach and parameterization is described in detail in Garces et al. (this volume).

Data Sources

The main source of quantitative information used in determining input parameters for the Ecopath model was the results of the Resource and Ecological Assessment Investigations of San Pedro Bay in 1994 - 95, spearheaded by the Institute of Marine Fisheries and Oceanology (College of Fisheries, University of the Philippines in the Visayas). These include reports of (Armada 1996; Babaran et al. 1997; Batang 1996; Villoso 1996) and others. The trawl and fisheries surveys conducted by (Armada 1996), in particular, provided most of the information used in the analyses. The systematic trawl survey, covering 16 stations with monthly sampling, was conducted from June 1994 to May 1995. A total of 192 species of fishes and invertebrates were recorded during the survey, with 9 species of small fishes of the Leiognathi-didae family comprising more than 60% of the total catch.

Other sources of information for deriving many of the input parameters include (Armada 1996) (Aliño et al. 1993) and also include other papers in (Christensen and Pauly 1993; Opitz 1996).

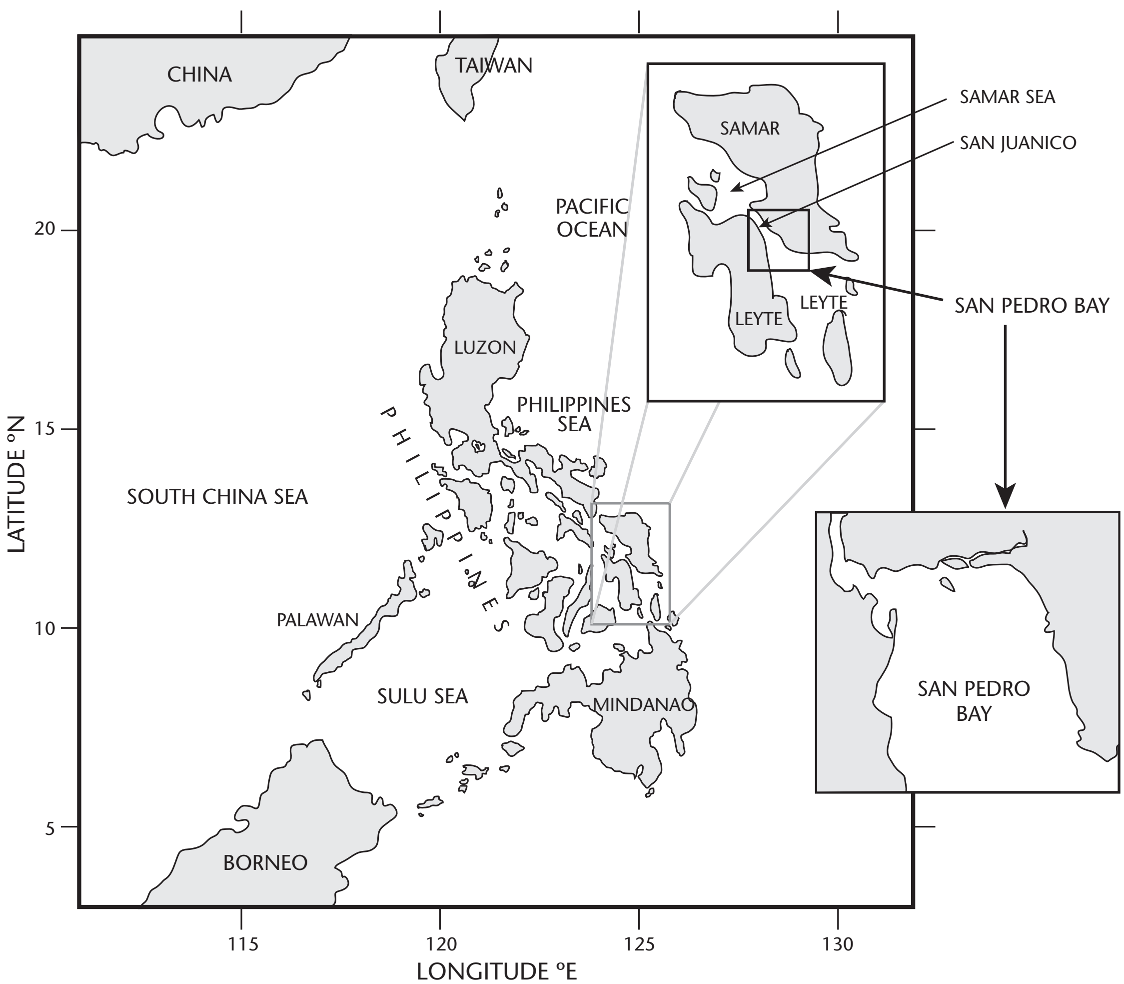

Fig. 1. Map of San Pedro Bay, Leyte, Philippines.

Ecological Groupings

A total of 13 consumer (fishes and invertebrates), 2 producer and 1 detritus groups were used in the analysis. The taxonomic composition of the ecological groups is given in Table 1.

Model Parameters

Biomass

The abundance or density information for most of the groups used in the analyses were either of limited reliability, (e.g. pelagic species caught by trawls), or in a form not readily convertible to biomass, (e.g. numbers without the corresponding species or size information), therefore only two biomass estimates were provided as input into the Ecopath model. These were for Leiognathids and for phytoplankton. The basic input parameters are shown in Table 2.

Using average CPUE values of the trawl survey, average demersal trawlable biomass was estimated at 2.4 $t{\bullet}km^{-2}$, using a catch efficiency of 70% for trawls (Armada 1996), with Leiognathids comprising over 60% of this. The biomass for this group was estimated at approximately 1.5 $t{\bullet}km^{-2}$. For phytoplankton, (Babaran et al. 1997) report a year-round mean chlorophyll *a* concentration of 0.153 $mg{\bullet}l^{-1}$ (n = 9 monthly values, s.d. = 0.121). This is equivalent to a water column concentration of 0.153 $g{\bullet}m^{-2}$. To convert this to the standard unit of measurement used in the model (wet weight in $t{\cdot}km^{-2} = g{\cdot}m^{-2}$), conversion factors reported in the literature were used. A factor of 25 was used to convert g chl *a* to g C (Parsons et al. 1984), while the factors 2.5 and 5 were used to convert g C to g dry weight, then to g wet weight, respectively (Browder 1993). Phytoplankton biomass was thus approximately 48 $t{\bullet}km^{-2}$.

Some biomass information for seagrasses is available from (Batang 1996), but no useful information is available for macroalgae in the bay. Furthermore, the estimated area coverage (in ha) of the major bottom communities, i.e. reefs and seagrass beds (Villoso 1996) appears to be too small to allow meaningful estimates of macrophyte biomass.

Table 1. Taxonomic composition of groups used in the analysis.

Ecological group	Representation taxa
Sharks	Elasmobranchs
Pelagic medium predator	*Auxis* spp, Carangidae, Scombridae, Sphyraenidae, Belonidae
Demersal medium predator	Serranidae, Lutjanidae, Lethrinidae, Pomadasyidae, Sciaenidae
Pelagic small predator	Caesionidae, Carangidae, Hemiramphidae
Demersal small predator	Synodontidae, Acanthuridae, Nemipteridae, flatfish, reef associated fish, Teraponidae
Demersal Small omnivores	Mullidae, Gerreidae, reef associated fish
Ponyfish	Leiognathidae
Squid	Squid, cuttlefish & octopus
Pelagic planktivore	Clupeidae, Engraulidae
Macroepifauna	Macrocrustaceans, echinoderms, etc.
Benthic infauna	Polychaetes, mollusks, etc.
Zooplankton	
Demersal herbivores	Siganidae
Phytoplankton	
Macrophytes	Seagrasses & seaweeds
Detritus	

Table 2. Basic input parameter values used in the analysis.

Ecological group	Biomas (t·km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	EE	Catch (t·km^{-2}·year^{-1})
Sharks		1.0	4.0	0.75	0.14
Pelagic medium predator		3.5	10.0	0.50	0.35
Demersal medium predator		3.5	12.5	0.80	0.58
Pelagic small predator		3.5	17.5	0.80	0.61
Demersal small predator		4.0	15.0	0.90	1.47
Demersal small omnivores		4.0	15.0	0.90	0.62
Ponyfish	1.5	4.0	17.5	0.90	1.16
Squid		3.0	15.0	0.80	0.31
Pelagic planktivore		3.5	20.0	0.95	0.73
Macroepifauna		2.5	24.0	0.95	0.83
Benthic infauna		5.0	20.0	0.95	0.07
Zooplankton		35.0	150.0	0.95	–
Demersal herbivores		2.0	10.0	0.95	0.37
Phytoplankton	48.0	140.0		0.80	–
Marcophytes		15.0		0.50	–
Detritus					

Note: P/B = Production/Biomass ratio, Q/B = Consumption/Biomas ratio, EE = ecotrophic efficiency.

Other Input Parameters

Values for most of the other input parameters were taken from different sources, including description of other ecosystem models in (Christensen and Pauly 1993). Estimates of total mortalities (Z) for representatives of the various fish groups were used as first approximations of the P/B ratios, while P/B ratios for the invertebrate and other consumer groups were based on turnover rates reported in the literature (Christensen and Pauly 1993). Turnover rates for seagrasses and macroalgae were taken from (Aliño et al. 1993). Initial estimates for phytoplankton were derived using mean primary production rates for Pacific shelf areas (= 0.52 g C•m^{-2}•day^{-1}; Mann 1982), the relevant conversion factors mentioned above, and the phytoplankton biomass estimate for the study area was 48 g•m^{-2} wet weight.

Consumption rates (Q/B; year^{-1}) were computed based on assumed gross efficiency rates ranging from 0.2 to 0.3 (Aliño et al. 1993). Initial EE values were all assumed. A range of 0.90 to 0.95 was assumed for groups 5 to 14, since it is believed that production in these groups is consumed (via predation and fishery harvest) almost entirely within the system. Slightly lower EE values were assumed for groups capable of more mobility, (e.g. pelagics and large demersal predators). A few initial runs were conducted to balance the model. The basic input parameters shown in Table 2 are those that lead to a balanced model.

Fishery Catch

Catch data for the various groups used in the analyses were taken from (Armada 1996). Total catch for the various gear types employed in the bay collectively amount to an annual average of 7.24 t•km^{-2}•year^{-1}.

Diet Composition

Data for diet compositions were taken from unpublished gut content studies, FishBase (Froese and Pauly 2000), and from reports in the literature (Aliño et al. 1993; Opitz 1996; Silvestre et al. 1993); the diet composition data used are given in Table 3.

Table 3. Diet composition of the 13 ecological groups used in the Ecopath analysis. Predator numbers refer to the prey numbers. See Table 1 for definition of groups.

	Predator												
Prey	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Sharks	0.050	0.001	–	–	–	–	–	–	–	–	–	–	–
2 Pelagic medium predator	0.325	0.150	0.010	0.010	–	–	–	0.010	–	–	–	–	–
3 Demersal medium predator	0.075	0.140	0.030	0.028	–	–	–	–	–	–	–	–	–
4 Pelagic small predator	0.100	0.180	0.050	0.050	–	–	–	0.010	–	–	–	–	–
5 Demersal small predator	0.075	0.050	0.072	0.010	0.012	–	–	0.005	–	–	–	–	–
6 Demersal small omnivores	0.075	0.050	0.062	0.010	0.013	0.005	–	0.005	–	–	–	–	–
7 Ponyfish	0.100	0.030	0.035	0.020	0.053	0.042	0.050	0.005	–	–	–	–	–
8 Squid	0.075	0.020	0.025	0.056	0.010	0.010	0.008	0.020	–	–	–	–	–
9 Pelagic planktivore	0.050	0.212	0.038	0.250	–	–	–	0.060	–	–	–	–	–
10 Macroepifauna	0.050	–	0.300	0.046	0.362	0.352	0.049	0.300	–	–	–	–	0.094
11 Benthic infauna	–	–	0.263	0.205	0.250	0.300	0.383	0.160	–	0.375	0.050	–	0.094
12 Zooplankton	–	0.167	0.075	0.230	0.300	0.167	0.410	0.400	0.650	0.050	0.175	0.200	0.072
13 Demersal herbivores	–	–	0.010	0.005	–	–	0.005	–	–	–	–	–	0.010
14 Phytoplankton	–	–	–	0.080	–	–	0.048	–	0.200	–	0.025	0.700	0.014
15 Marcophytes	–	–	–	–	–	0.044	–	–	–	–	–	–	0.684
16 Detritus	0.025	–	0.030	–	–	0.080	0.047	0.025	0.150	0.575	0.750	0.100	0.032

Results and Discussion

Trophic Model

Figure 2 presents the trophic structure of the coastal fisheries of San Pedro Bay as defined here.

The basic estimates are shown in Table 4, while a summary of the estimated ecosystem parameter values are presented in Table 5. Figure 3 presents a mixed trophic impact analysis for the ecosystem, i.e. it quantifies all direct and indirect trophic impacts (predation, competition or fishing), and also can be seen as a sensitivity analysis.

The biomass estimates for the small pelagic groups are rather close to the initial estimate for Leiognathids, the dominant group among demersal fishes. Pelagic small predators (1.24) and squid (1.01) have biomass estimates slightly less than the dominant group, while the estimate for pelagic planktivores (2.68 t•km-2), is about 80% higher than that for Leiognathids.

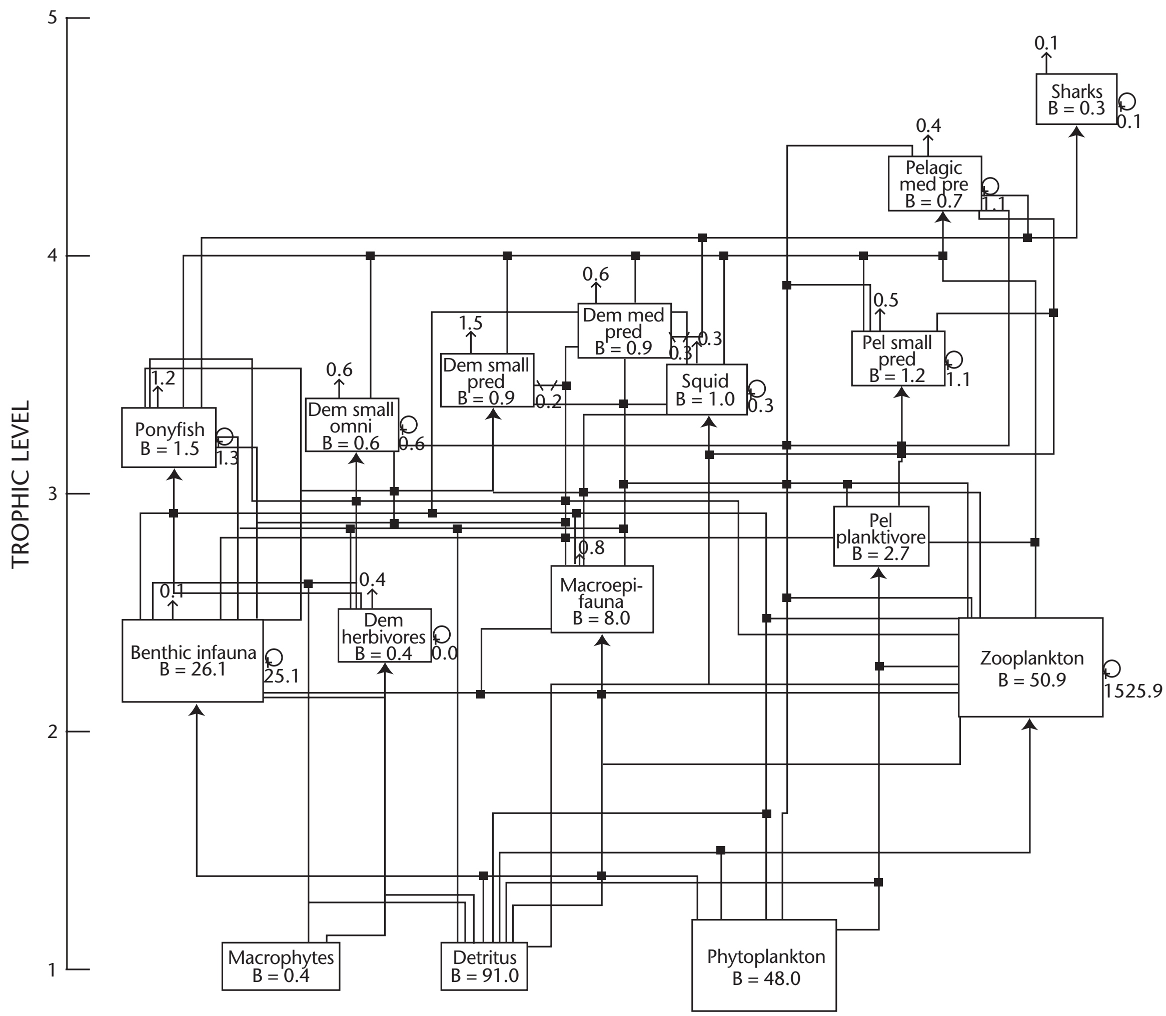

Fig. 2. Flow chart of the food web of San Pedro Bay, Philippines. Only flows exceeding 0.1 t·km^{-2}·year^{-1} are shown. The groups are arranged by trophic level on the Y-axis, and the size of the boxes is a function of the group biomass.

Table 4. Parameter inputs and outputs (in parentheses) from the Ecopath analysis.

Ecological group	Biomas ($t{\cdot}km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	Annual landing ($t{\cdot}km^{-2}{\cdot}year^{-1}$)	Tropic Level	Omnivory Index
Sharks	(0.27)	1.0	4.0	0.75	0.14	(4.6)	(0.48)
Pelagic medium predators	(0.73)	3.5	10.0	0.89	0.35	(4.3)	(0.41)
Demersal medium predators	(0.88)	3.5	12.5	0.85	0.58	(3.7)	(0.33)
Pelagic small predators	(1.24)	3.5	17.5	0.88	0.61	(3.5)	(0.42)
Demersal small predators	(0.86)	4.0	15.0	0.92	1.47	(3.5)	(0.08)
Demersal small omnivores	(0.60)	4.0	15.0	0.95	0.62	(3.3)	(0.28)
Ponyfish	1.50	4.0	17.5	0.79	1.16	(3.2)	(0.21)
Squid	(1.01)	3.0	15.0	0.91	0.31	(3.4)	(0.16)
Pelagic planktivore	(2.68)	3.5	20.0	0.97	0.72	(2.8)	(0.36)
Macroepifauna	(8.01)	2.5	24.0	0.96	0.83	(2.5)	(0.40)
Benthic infauna	(26.14)	5.0	20.0	0.95	0.07	(2.3)	(0.28)
Zooplankton	(50.86)	35.0	150.0	0.95	0.0	(2.2)	(0.25)
Demersal herbivores	(0.38)	2.0	10.0	1.00	0.37	(2.4)	(0.37)
Phytoplankton	(48.00)	140.0	(0.0)	0.80	0.0	(1.0)	(0.0)
Marcophytes	(0.40)	15.0	(0.0)	0.50	0.0	(1.0)	(0.0)
Detritus	0	–	–	(0.41)	0.0	(1.0)	(0.41)

Note: P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = Ecotrophic efficiency.

Table 5. Summary of ecosystem parameter values.

Parameter	Value
Sum of all consumption:	8 519.19
Sum of all exports:	1 879.81
Sum of all respiratory flows:	4 846.14
Sum of all flows into detritus:	3 150.90
Total system throughput:	18 396.03
Sum of all production:	8 695.16
Calculated total net primary production:	6 725.94
Net system production:	1 879.81

Parameter	Value
Total primary production/total respiration:	1.39
Total primary production/total biomass:	46.81
Total biomass/total throughput:	0.008
Total biomass (excluding detritus):	143.67
Total catches:	7.24
Gross efficiency (catch/net p.p.):	0.0011
Connectance Index:	0.45
System Omnivory Index:	0.29

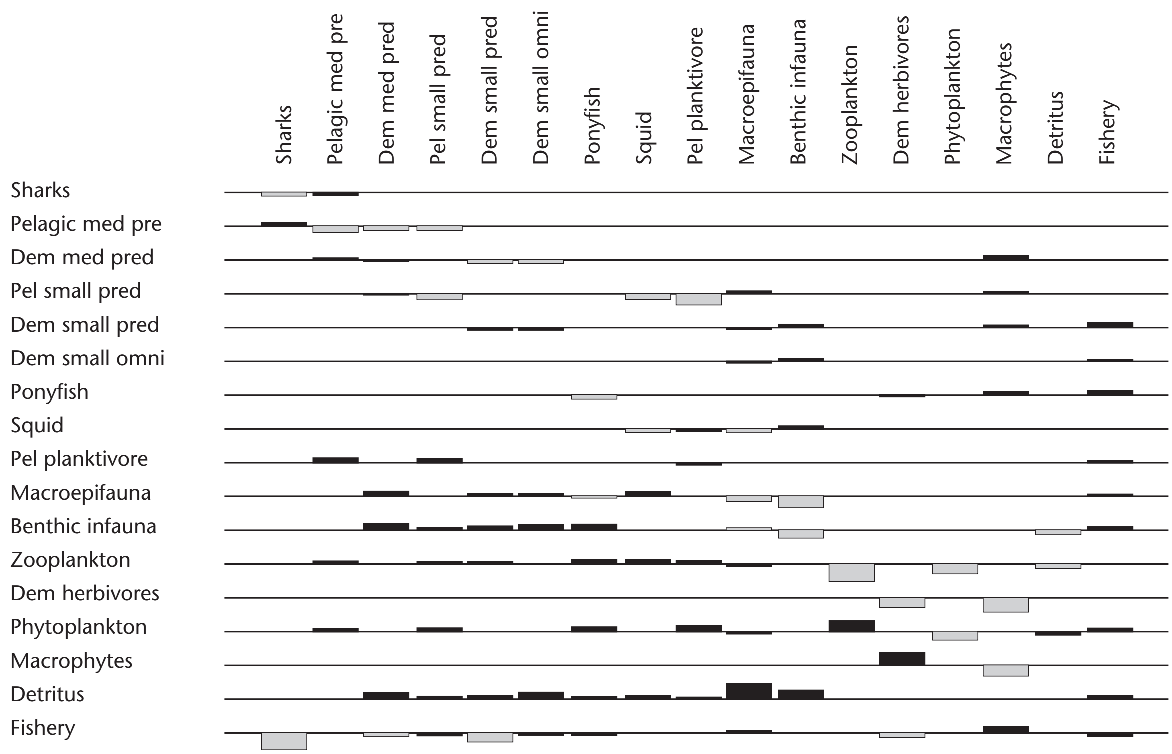

Fig. 3. Mixed trophic impacts in Pedro Bay ecosystem, Philippines. The graph shows the direct or indirect trophic impacts the groups to the left (rows) have on the groups mentioned above (columns). Positive impacts are shown above the baseline, and negative below. The impacts are relative but comparable between groups.

Under the steady state assumption, estimates of total mortality (Z) are reasonable estimates of turnover rates (P/B ratios). Almost all stock assessment results for the Philippines (Armada 1994; Armada 1996; Armada et al. 1983; Federizon 1993; Silvestre et al. 1991; Silvestre et al. 1987; Silvestre et al. 1994) show high total mortality (Z) estimates for the fish groups, reflecting heavy exploitation of the various fishing grounds. Productive ecosystems are able to maintain high energy flows (productivity) with fast turnover rates, even if biomass levels are quite low. The P/B ratios used in the present analyses are consistent with the assessment of (Armada 1996) that the annual total catch from the bay amounts to three (3) times the estimated biomass. Compared with other investigations, however, biomass estimates for San Pedro Bay are comparable to those in less exploited coastal areas in the region, (e.g. Brunei Darussalam, (Silvestre et al. 1993). It appears that San Pedro Bay still maintains a high fishery potential (using biomass as an indicator of harvestable amount) in spite of what appears to be heavy fishing pressure (Armada 1996). This is similarly suggested by the mortality coefficients (Table 6) computed using data on food consumption, assumed ecotrophic efficiencies, harvested amounts, and employed turnover rates. Except for groups 1 (sharks), 5 (demersal small predators) and 13 (demersal herbivores), derived exploitation rates are generally below 0.25%, which is not consistent with a conclusion of heavy exploitation. This indicates that the assumption of steady state conditions may be unrealistic for San Pedro Bay.

Ecosystem Characteristics

A summary of the statistics are presented in Table 5. Total throughput is estimated at 18 396 t•km^{-2}•year^{-1}. Biomass estimates for the various trophic levels are shown in Table 7, with a total value of 144 t•km^{-2} (excluding detritus). Hence the total amount of (potential) energy that passes through the system (consumption plus exports) is about 128 times the estimated biomass of the living components, a value very close to the P/B ratio derived by the model for the phytoplankton. Using the empirical

Table 6. Instantaneous mortality coefficients (year^{-1}) computed for the various groups. (Z refers to total mortality which, under steady state conditions, is approximated by production/biomass ratio; F refers to fishing mortality and is based on fishery harvest estimates; E is the exploitation rate which is equal to F/Z; M2 and M0 refer to components of natural mortality due to predation and other causes, respectively).

Ecological group	Z	F	E	M0	M2
Sharks	1.0	0.52	0.52	0.25	0.23
Pelagic medium predators	3.5	0.48	0.14	0.38	2.64
Demersal medium predators	3.5	0.66	0.19	0.54	2.30
Pelagic small predators	3.5	0.49	0.14	0.42	2.59
Demersal small predators	4.0	1.72	0.43	0.31	1.97
Demersal small omnivores	4.0	1.04	0.26	0.21	2.75
Ponyfish	4.0	0.77	0.19	0.84	2.39
Squid	3.0	0.31	0.10	0.27	2.42
Pelagic planktivore	3.5	0.27	0.08	0.12	3.11
Macroepifauna	2.5	0.10	0.04	0.11	2.29
Benthic infauna	5.0	0	0	0.25	4.75
Zooplankton	35.0	0	0	1.75	33.25
Demersal herbivores	2.0	0.97	0.49	0	1.03
Phytoplankton	140.0	0	0	28.00	112.00
Marcophytes	15.0	0	0	7.50	7.50

formula of (Pauly et al. 1993), biomass of detritus is estimated at about 259 t•km^{-2}, about 1.8 times the total biomass estimated for all living components. Interestingly, only 27% of the total throughput originates from detritus, while the rest is derived primarily from phytoplankton production (Table 8). The latter is consistent with the resulting high biomass estimates of pelagic groups.

Other derived parameters are indicative of an ecosystem in a stage of development, and therefore inconsistent with steady-state (mature) conditions (Odum 1971). These include a relatively high P/R ratio (1.39), relatively high net system production

Table 7. Biomass estimates per trophic level.

Trophic Level	Biomass (t·km^{-2})
Level I	48.40
Level II	78.52
Level III	13.90
Level IV	2.45
Level V	0.36
Level VI	0.04
Level VII	< 0.01

Table 8. Flow estimates (total consumption, exports, flows to detritus, and respiration) originating from detritus and primary producers. Units are t·km^{-2}·year^{-1}.

Flow	Detritus	Primary producers	Combined
Total consumption	1 402	5 555	6 957
Export	1 876	3	1 879
Flow to detritus	342	2 808	3 150
Respiration	931	3 914	4 846
Throughput	4 553	12 281	16 834
% contribution to total throughput	27.0	73.0	

(1 880 t•km^{-2}•year^{-1}) or export in comparison with other coastal areas, low biomass to throughput ratio (0.008), high respiration to biomass ratio (33.7), relatively low omnivory index (0.29), and high overhead from internal flow (57.4% of total capacity). These indicators are consistent with a system where moderate (or tolerable) exploitation generally drives back development to earlier stages (Odum 1971).

While the results of the modelling effort are only preliminary, valuable insights are provided. Of special interest is the high system throughput to biomass ratio (128 year^{-1}), which reflects the high model-derived turnover rate for phytoplankton (140 year^{-1}). This suggests that the system is essentially phytoplankton-based. San Pedro Bay lies in the interior of the larger Leyte Gulf, which opens into the Pacific Ocean, and is linked to the Samar Sea further north via the San Juanico Strait between the islands of Leyte and Samar. It is thus likely that a considerable amount of water is exchanged between these two much larger bodies of water through the bay. As such, considerable inputs and exports (immigration and emigration) can be expected, particularly from pelagic groups. This is consistent with the estimated large net export of the bay. Hence, the derived high phytoplankton turnover rate reflects the magnitude of water exchange (input and export) passing through the bay. It is therefore possible that the apparent lower fishery catches of pelagic groups in San Pedro Bay may be due to movement, in and out of the area.

Fisheries Management Implications

The major interesting result from the analyses is that San Pedro Bay does not appear to be as heavily exploited, as the employed P/B ratios (= Z) would imply. In comparison to other trawl fishing grounds in the country, (Armada 1996) showed that current extraction rates in San Pedro Bay (3 times existing biomass) are lower than those in other traditional fishing grounds such as Manila Bay and San Miguel Bays and Lingayen Gulf. The results also indicate that the fisheries potential for pelagic species groups might be higher than currently considered. However, it should be clear that increased fishing will lead to increased 'fishing down the food web' and that catch will be increasingly dominated by less valuable low trophic level species and variability, sending a warning that increased fishing effort may be problematic.

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