

TROPHIC DYNAMICS OF A FLORIDA KEYS CORAL REEF ECOSYSTEM

J.M. Venier¹ and D. Pauly^{1,2}

¹ Fisheries Centre, University of British Columbia,
2204 Main Mall, Vancouver, B.C. V6T 1Z4, Canada

² International Center for Living Aquatic Resources Management (ICLARM),
MC P.O. Box 2631, 0718 Makati, Metro Manila, Philippines

ABSTRACT

A trophic model of the Looe Key National Marine Sanctuary, Florida, U.S.A. (=30 km²) was constructed, using the ECOPATH II approach for construction of mass-balance ecosystem models, the results of local biomass surveys by J. Bohnsack and collaborators and a structure adapted from an earlier ECOPATH II model, by S. Opitz, of a Virgin Island coral reef. Flows of energy and other relationships between the 20 functional groups in the system were examined (9 fish groups, 11 non-fish groups), then compared with those in five other coral reef ecosystem models. The Looe Key reef has the best recycling of detritus and is hence the most "mature" of the coral reef systems so far studied. Improvements of the model will consider seasonal changes of biomass and other system variables, and uncertainty in parameter inputs, using a semi-Bayesian approach. The impact of various management measures can then be simulated, using a new dynamic subroutine (EcoSim) of ECOPATH.

INTRODUCTION

It has long been appreciated that "nearly all [species] either prey on or serve as prey for others.[...and] that each organic being is either directly or indirectly related in the most important manner to other organic beings..." (Darwin 1872). Translating this observation into an operational research program has not been easy for ecologists, particularly for those working on coral reefs, whose very high diversity of species, with consequent diversity of trophic and other interactions, may seem to defy the reductionist assumptions required for quantitative modelling (Pauly and Christensen 1994). However, two modelling approaches have emerged and successfully applied to coral reef systems: 1) simulation models (McClanahan 1995) and 2) mass-balance models (Polovina 1984; Christensen and Pauly 1992). Moreover, the latter approach, which is generally straightforward to implement, has recently been shown to facilitate the parameterization of simulation models (Walters et al. submitted), thus opening up an avenue for the routine application of simulation modelling to complex ecosystems such as coral reefs.

We present here an application of the mass-balance approach to reefs in the Looe Key National Marine Sanctuary, as a prelude to a study of its response to management interventions, using the simulation module (EcoSim) of the ECOPATH software.

MATERIALS AND METHODS

Looe Key reef is located approximately 13 km off of Big Pine Key, Florida, U.S.A. The sanctuary proper comprises an area of approximately 30 km² (Bohnsack et al. 1987) and includes the reef itself, and surrounding coral, sand and seagrass habitats (Wheaton and Jaap

1988). The sanctuary is a popular location for diving and snorkeling and is subjected to heavy use throughout the year. Although hook-and-line fishing is allowed within the sanctuary boundaries, the harvest is very small and was not considered in the version of the model presented here.

Although many studies have been conducted on the various components of Florida reef ecosystems, no comprehensive ecosystem models have been constructed so far. Looe Key was chosen as a representative reef for the Florida Reef Tract, which runs from Miami southwest to the Dry Tortugas, both because of the research conducted in and around it and because the first author is familiar with it from diving visits.

The mass-balance approach implemented in the ECOPATH software (we used its newly released version 3.0; Christensen and Pauly 1996) relies on the master equation

$$B_i * (P/B)_i * (EE)_i = (Catch)_i + \sum B_j * (Q/B)_j * DC_{ji} \quad \dots 1)$$

where B is the mean biomass of functional group i during the period under consideration, P/B_i is its production/biomass ratio, EE_i its ecotrophic efficiency (ie., the fraction of its production consumed within the system), Q/B_i its food consumption per unit biomass and DC_{ji} the fraction of prey i consumed by predator j.

The data required to parameterize the model were obtained from the published literature on Florida reefs where possible, but also on the greater Caribbean Sea and other areas, due to substantial gaps in the published Florida database. Following Opitz (1993), species groups were aggregated into 20 boxes representing functional groups, ie., 9 fish and 11 non-fish groups. The fish groups' definition and biomasses were based on a visual census study by Bohnsack et al. (1987) that estimated the abundances of the 188 species occurring within the sanctuary boundaries. Non-fish taxa input values were from a diverse array of sources, documented in Opitz (1991, 1993). The data were converted into the common currency (t wet weight km² year⁻¹) before entry into ECOPATH, using conversion factors in Atkinson and Grigg (1984) and in the contributions in Christensen and Pauly (1993).

The system of equation (1) allows one entry per group to be left unknown, to be estimated through the mass-balance requirement. The unknowns here were the EE values, or the biomasses (the majority of the latter in cases where visual survey estimates were unavailable); P/B and Q/B values were estimated using the empirical relationships of Pauly (1980) and Palomares and Pauly (1989).

The biomasses estimated after successive runs of ECOPATH were accepted only when they generated thermodynamically acceptable values of EE (≤1). The diet matrix (not shown) can be inferred from Fig. 1.

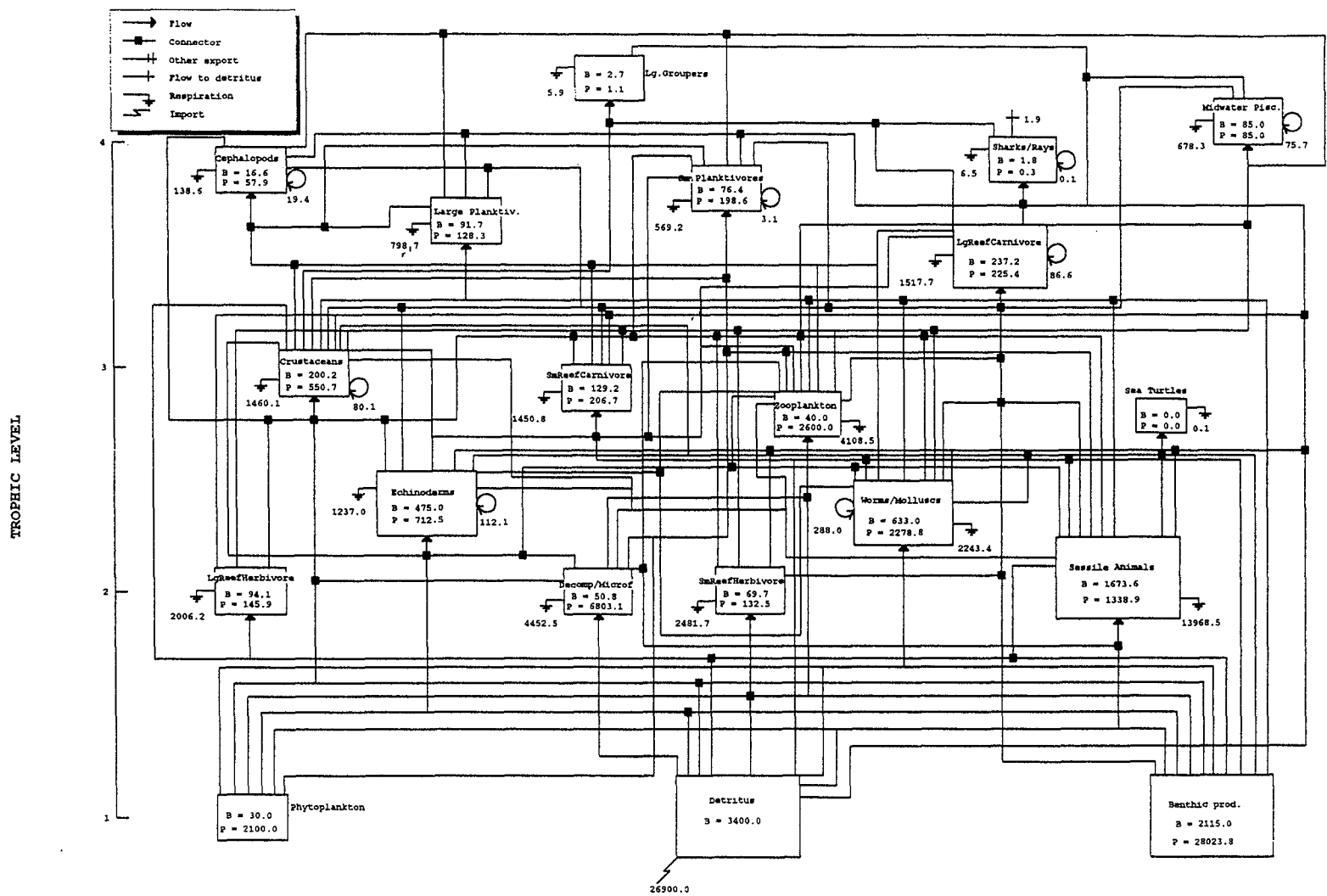


Fig. 1: Trophic flow diagram of the Looe Key National Marine Sanctuary ecosystem. Flows are in $t \cdot km^{-2}$. Backflows to the detritus and other lesser flows are not shown. The area of the boxes is proportional to the logarithm (B; in $t \cdot km^{-2}$) of the biomasses of the groups they represent. The boxes are arranged by trophic level on the y-axis. Consumption flows entering a box do so at the bottom while those which represent predation on a box exit from the top and sides.

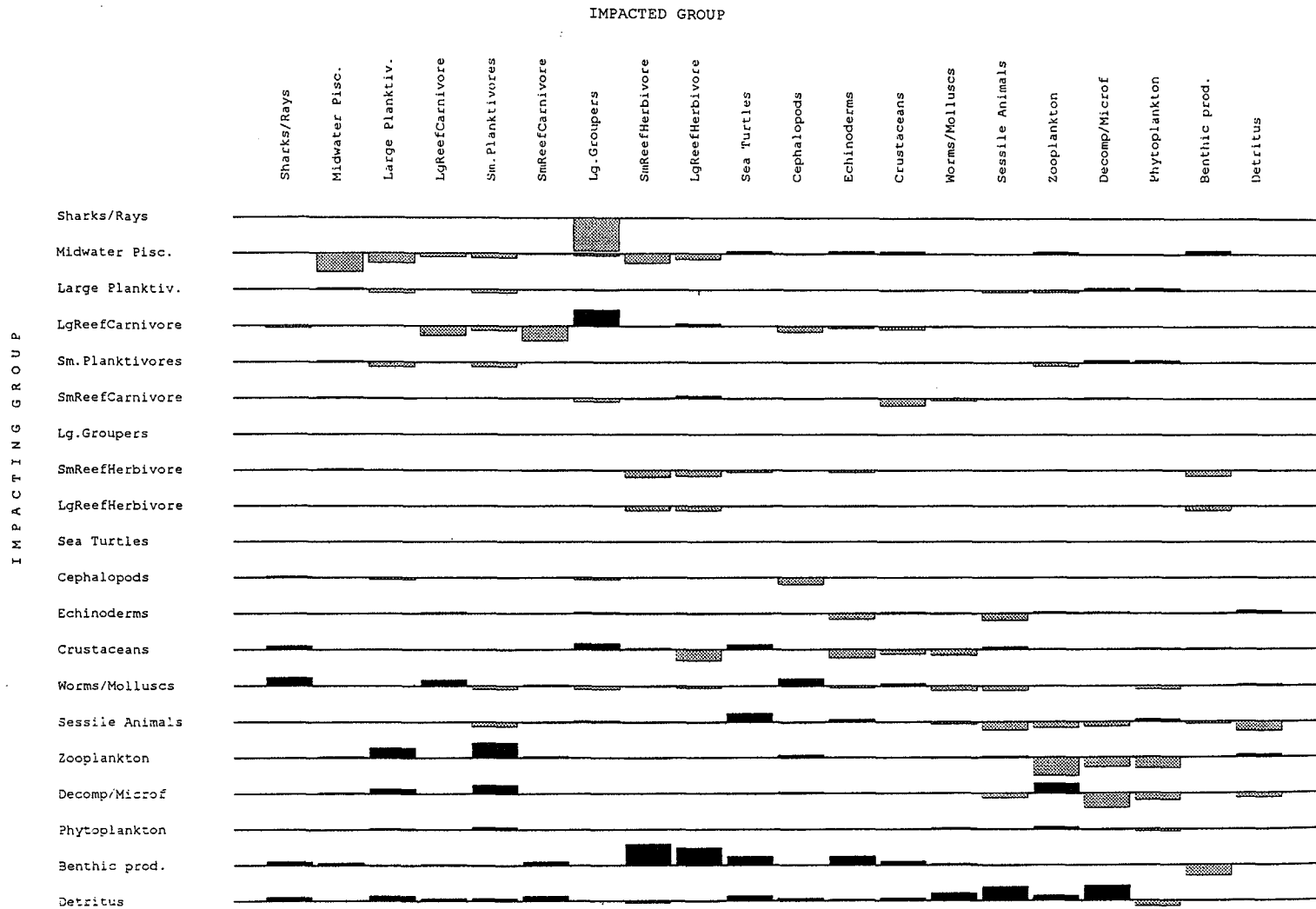


Fig. 2: Mixed trophic impacts in the Looe Key ecosystem. Positive impacts reflect relative increases in biomass while the converse is true of negative impacts. Note the high number of impacts, both positive and negative, which occur at the lower trophic levels. The histograms are reflective of the interdependencies of all groups within the ecosystem.

Table 1: Inputs and outputs (in parentheses) of the Looe Key National Marine Sanctuary ECOPATH model.

Group	B (t·km ⁻²)	P/B (year ⁻¹)	Q/B (year ⁻¹)	EE
1. Sharks & Rays	1.75	0.18	4.90	(0.47)
2. Midwater Piscivores	85.00	1.00	8.90	(0.92)
3. Large Planktivores	(91.67)	1.40	10.00	0.92
4. Large Reef Carnivores	(237.24)	0.95	7.30	0.95
5. Small Planktivores	(76.38)	2.60	10.00	0.98
6. Small Reef Carnivores	(129.17)	1.60	12.80	0.98
7. Large Groupers	(2.68)	0.40	2.30	0.20
8. Small Reef Herbivores	(69.74)	1.90	37.45	0.98
9. Large Reef Herbivores	(94.14)	1.55	22.80	0.96
10. Sea Turtles	0.02	0.15	3.50	(0.00)
11. Cephalopods	(16.55)	3.50	11.70	0.95
12. Echinoderms	475.00	1.50	4.00	(0.93)
13. Crustaceans	(200.25)	2.75	10.00	0.99
14. Worms & Molluscs	(633.00)	3.60	7.00	0.96
15. Sessile Animals	1673.58	0.80	9.00	(0.82)
16. Zooplankton	40.00	65.00	165.00	(0.96)
17. Decomposers & Microfauna	(50.77)	134.00	215.00	0.95
18. Phytoplankton	30.00	70.00	-	(0.89)
19. Benthic Producers	2115.00	13.25	-	(0.31)
20. Detritus	3400.00	-	-	(0.84)

RESULTS AND DISCUSSION

Several of the input parameters required strong adjustments to achieve mass-balance. In particular, the biomass of several groups of small fishes had to be increased, and nearly doubled in one case. This is not surprising, as the stationary visual sampling technique used for Looe Key fishes (see Bohnsack and Bannerot 1986; Bohnsack et al. 1987) provides only conservative minimum estimates of relative abundance (J. Bohnsack pers. comm.). Opitz (1991) also had to increase her initial estimates of biomass for small, cryptic species, for the same reason.

Fig. 1. presents a flow diagram of the Looe Key ecosystem and illustrates its high number of trophic links and the resulting complex network flows: a characteristic of coral reef systems. Most species groups feed at more than one trophic level, leading to the numerous indirect interactions illustrated in Fig. 2, where the relative impact that each group has on the others is represented.

Overall, the Looe Key ecosystem is characterized by high ecotrophic efficiency and high biomass values. This is achieved by a high degree of detritus recycling (13.1%), the highest value so far calculated for any coral reef system (Fig. 3). This, jointly with a high productivity/respiration ratio (Fig 3), defines Looe Key Reef as an ecosystem that is highly mature, according to the concept of Odum (1969) reinterpreted by Pauly and Christensen (in press) and Christensen and Pauly (submitted).

It is planned to refine this model by considering seasonal changes in the parameters of equation (1) (especially P/B, Q/B), as mediated by temperature changes (summer-winter difference at Looe Key = 10°C), and any observed seasonal changes in biomass, diet composition or other biological characteristics. Additionally, we will use the model in Fig. 1 as the basis for a simulation model, wherein the parameters of the system of linear equations in (1) define a system of differential equations that can be integrated over time (Walters et al. submitted).

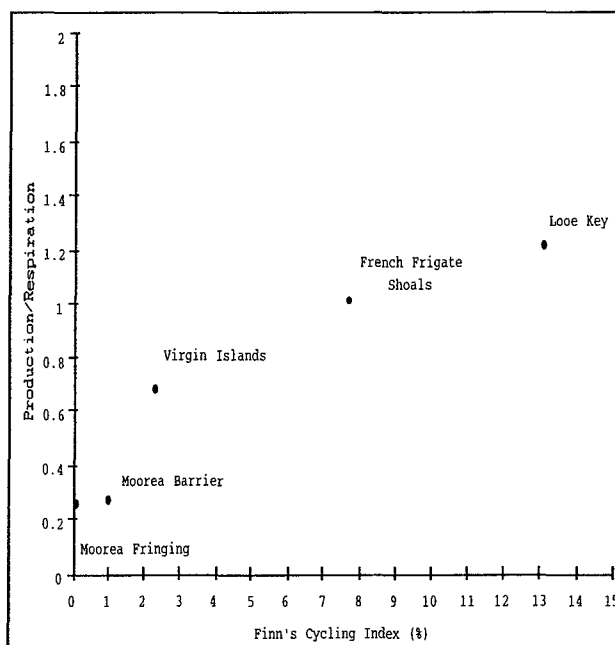


Fig. 3: Relationship between two indices usually increasing with increasing ecosystem maturity: Total system primary production/respiration ratio vs Finn's cycling index, expressing the % of total detritus flow that is recycled (U.S. Virgin Islands: Opitz 1993; Moorea Fringing and Barrier Reefs: Arias-Gonzalez 1993; French Frigate Shoals: Polovina 1984; Looe Key: this study).

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