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CURRENTS

CORAL REEF SYSTEMS AND THEIR EXPLOITATION: TOWARDS A GLOBAL ACCOUNT

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The editors of *Reef Encounter* asked us to highlight - with emphasis on coral reefs - the key results of our recent study on 'the primary production required to sustain global fisheries' (Pauly and Christensen, 1995). As authors often do when asked to review the work of others, we shall digress, and present extraneous matters related to our work. This is not a problem here, however, since we are both the reviewer and the reviewees.

The above-cited study, rather than asking the old question: 'How much catch can be sustainably extracted from the world oceans, given an estimate of global primary production (PP)?', presented estimates of the primary production required (PPR) to sustain existing fisheries catches, and the enormous levels of discarded by-catch. Our study also differed from earlier attempts, in that we analyzed disaggregated data (39 groups of fish, each with their own catch and trophic levels, in 6 different ecosystem types), a feature which strongly, and positively affected the accuracy and precision of our estimates (Pauly, in press).

For coastal and coral reef systems (which we treated as a single system type, given the state of global fisheries statistics), we estimated a PPR of 8.3% of observed PP, higher than for open ocean systems (2%), but markedly lower than for upwelling (25%) and shelf systems (24-35%), which came close to the high values reported from terrestrial systems (Vitousek *et al.* 1986). We attributed the low PPR of coastal/reef systems to (a) the usually depleted biomasses of, and hence reduced catches from these systems, and (b) the fact that the high fisheries catches in coastal systems often depend on organisms low in food webs (e.g. clupeids, bivalves). We should also have added, with special reference to coral reefs, that fisheries catches are often underestimated in the FAO (nominal) catch statistics upon which our study was based, not to mention the gleaning of small fish and invertebrates by women and children, which hardly ever shows up in such statistics. Yet, it is usually high, and occasionally exceeds nominal catches (Chapman, 1987).

The approach we used differed radically from those used earlier to estimate global fisheries potentials from the 'bottom up', via *guessed* numbers of trophic levels, *guessed* transfer efficiencies between trophic levels, and *guessed* ratios of fish production to potential fish catches (review in Pauly, in press). Rather, besides inverting the traditional approach (and predicting PPR from catches, not catches from PP), we used mass-balance models, representing the trophic fluxes between the elements of 48 aquatic ecosystems, grouped in six ecosystem types, to *calculate* the parameters values guessed by earlier authors. The accuracy of our results thus depends entirely on the validity of the ECOPATH II approach and software (Christensen and Pauly, 1992), used to balance these 48 models - which is where we have to digress.

Though the ECOPATH II approach was initially developed for application to a coral reef system (Polovina, 1984), all subsequent applications to coral reefs were the results of work by our direct collaborators, or graduate students (see contributions in Christensen and Pauly, 1993, and Arias-Gonzalez, 1993), suggesting that coral reef scientists -- as opposed, for example, to fisheries scientists in general, or to freshwater biologists - may still have reservations about this approach. Yet it is built around two propositions about which few would be able to argue:

i. that in a coral reef, as in any other ecosystem, mass-balance must exist, i.e., that the biomass produced by the components of the ecosystem must be either consumed within the ecosystem, exported or otherwise accounted for; and
ii. that the biomass and rates (of production, mortality and consumption) reported in published accounts of single species within ecosystems must be compatible with the biomass and rates reported for their prey *and* their predators, for at least the period stated or implied in the relevant publications (Pauly and Christensen, 1994).

One reason for the reservation vis-a-vis the ECOPATH II approach may be our initial emphasis on the 'equilibrium' or 'steady-state' assumption seemingly implied in mass balance models. This assumption, in fact, is not really required, as long as mass balance is retained. Thus, the biomass of a species or group at the end of the period covered by a model does not need to be the same as at the beginning. Neither is it necessary for seasonal changes of biomass, production or food consumption to be ignored: they can be explicitly accounted for.

The latest (Windows) version of ECOPATH II includes routines which allow for considering such changes, and more will follow, for example, to facilitate the construction of seasonal models. Also, the Windows version, while capable of reading and analyzing files generated with the earlier, DOS version, incorporates a new Monte Carlo simulation routine, as required, for example to evaluate the precision of outputs in a (semi-) Bayesian context (Christensen and Pauly, 1995). These routines can be applied to all forthcoming coral reef models, e.g., to the model of Looe Key Reef, Florida, presently being constructed by Judson Venier, a graduate student at the Fisheries Centre, UBC, and, retroactively, to the detailed models constructed for example by Opitz (1995) and Arias-Gonzalez (1993).

As a related issue we are interested in drawing general conclusions on flow patterns in coral reef ecosystems. We are presently stratifying the world oceans into large marine ecosystems (LMEs). Based on information on global reef area from the ReefBase project (McManus *et al.*, 1995), we will then attribute relevant parts of the LMEs to coral reef ecosystems and use published mass balance models within the LMEs to raise flow patterns to both regional and global scales. What we expect is that through this quantification, the global importance of coral reefs for fish productivity will

become more apparent, as will the case for protecting reefs. Likewise, this approach, through the possibilities it offers for assessing the impact of different types of interventions, will represent a step towards ecosystem management, an issue whose importance is likely to increase in the near future.

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