Potential Yield Estimates for Reef and Slope Fisheries: A Review of Approaches and Their Limitations with Special Reference to the Caribbean

JOHN D. NEILSON[1], KARL A. AIKEN, and ROBIN MAHON[2]
CARICOM Fisheries Resource Assessment and Management Program
Pelagic and Reef Fish Resource Assessment Unit
Kingstown, St. Vincent and the Grenadines
West Indies
[1] Present Address:
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick
Canada E0G 2X0
[2] Present Address:
48 Sunset Crest
St. James, Barbados, WI

ABSTRACT

Studies of potential yield of reef fish from the Caribbean and Pacific regions are reviewed. The approaches taken to determine potential yield are described, and some of the sources of variation discussed. The apparently large difference in potential yield between the Caribbean and Pacific is considered largely artifactual, and probably related to the size of the study area. Based on the review, a range (1.7 -2.3 t/km^2/yr) of potential yields possible from reef fisheries on coralline shelves of the Caribbean is suggested. Recent landings of reef fisheries within the region are typically considerably less than the potential yield, indicating that with proper management, a significant increase in landings could be realised.

KEYWORDS: yield, reef, Caribbean, Pacific

INTRODUCTION

Since the work of Ryther (1969), who used data on primary production in the world's oceans to estimate potential fish yield, there has been considerable interest in the prediction of potential yield. Having such information is attractive in many ways. Potential yield data can be used as a basis for the rational development of a fishery, with the aim of ensuring that the now-familiar problem of fleet over-capacity does not occur. Accurate and precise description of the limits of production from wild stocks could also act as a catalyst for the development of alternative sources of animal protein, such as aquaculture. Projections of potential yield are also critically important in determining the feasibility of fisheries development projects. It has been noted that the failure of large-scale fisheries development projects in the Caribbean region can be linked to overly-optimistic estimates of potential yield (Goodwin, 1987).

However attractive, estimates of potential fish yield are often imprecise. For example, a critique of the Ryther paper demonstrated that those estimates of fish production could be incorrect by as much as two orders of magnitude (Alverson *et al.* 1970). Even when calculated using a reduced geographic scale such as coralline shelves or reefs, estimates of fish yield can also be imprecise. For example, estimates of yield per unit area of tropical shelf typically range from about 0.5 to 5.0 t/km^2/yr (Marten and Polovina 1982, Caddy and Sharp, 1986), but may be as high as 36.9 t/km^2/yr (Wass 1982).

In this paper, we evaluate the various approaches for the estimation of fish yield, using examples from tropical reef fisheries, with special reference to the Caribbean region. We critically review available literature, and based on such information, provide our interpretation of the potential yield of reef fish communities in the Caribbean, along with some measures of uncertainty. We view the latter as particularly important, since as noted by Goodwin (1987) and Bellwood (1988) there is often a tendency to give a single figure for potential yield, with no indication of the variability that applies to those values. We also update some predictive relationships between fish yield and factors such as depth and primary production that have been postulated, and review whether they still appear valid.

METHODS

As noted by Bellwood (1988) and Acosta and Recksiek (1989), many of the conflicting views concerning fish productivity of reefs may be traced to different definitions of what constitutes the fished area, and what species are included in the definition of exploited species. It is therefore important to define those terms as used here.

We considered reef fish to include members of families Serranidae, Lutjanidae, Acanthuridae, Chaetodontidae, Holocentridae, Labridae, Scaridae, Mullidae, Haemulidae, Branchiostegidae and Balistidae. The inclusion of snappers and groupers was to achieve consistency with available data within the Caribbean region, and also deals with the problem of whether to include the relatively shallow-water *Epinephelus* species. Small planktivorous species which sometimes occur on reefs (such as *Harengula* sp.) were not included in our compilation of landings of Caribbean countries. However, as noted throughout this paper, other workers use different conventions to describe reef and reef-associated fish.

For the purposes of determining potential yield, we used data on shelf areas for Caribbean countries reported in Mahon (1990) for St. Lucia, Dominica, St. Vincent and the Grenadines, and Grenada. In the case of Jamaica, the value used by Wolf and Rathjen (1974) was used, since Mahon (1990) did not provide a value for that country. While obvious, it is important to note that the shelf areas of Caribbean nations typically consists of variable substrate, with only a fraction being live coral. The implications of this observation when different sites are compared with respect to potential yield are discussed later. Whenever we refer to 't' or tons, we are referring to metric tons.

REVIEW OF RELATED LITERATURE

Within the available literature, two general categories exist. In the first instance, researchers have attempted to provide an analytical basis for their estimates of fish production. Such analyses have usually involved variants of the surplus production modelling approach. Alternatively, authors have employed descriptive or data-based approaches, providing information on fishery yield and assuming that current removals bears some relationship to potential yield. We review below selected examples of the two approaches.

Analytical Approaches To Estimating Fish Yield

Munro and Thompson (1973) — In formulating a unique variation of the surplus production model, Munro and Thompson were the first to develop an analytical model for tropical reef fisheries yield. Typically, surplus production models involve the fitting of a parabola to a plot of CPUE vs effort, and time series of such data are required. Munro and Thompson postulated that in place of a time series, observations of CPUE and effort could be obtained for discrete geographic units (in the Jamaica case developed in their paper, the geographic unit was parishes) and the response of the population to various levels of exploitation within each geographic unit could be assumed to reflect that of the larger population as fishing pressure varied over many years. In the Jamaican example presented by Munro and Thompson, the potential yield was considered 4.1 t/km^2/yr.

WECAFC/83/6 (see FAO 1983) — This anonymous report features an application of the Munro model to data from the Dominican Republic. An MSY of 2.5 t/km^2/yr is derived. However, inspection of the data suggests that the fit of the right-hand portion of the parabolic relationship is critically dependent on one point only. Any imprecision in the estimation of that value will have a drastic impact on the derived estimate of maximum yield per unit area.

Ardill (1983) — This paper examined the yield of fisheries located in the southwest Indian Ocean. Ardill also attempts a spatial surplus production approach, and derives a potential yield of about 5 t/km^2/yr. Relatively few details were provided regarding the derivation of the curve, however, probably due to the editorial policies of the journal in which the work appears. The relationship also suffers from the same drawback of the one postulated for the Dominican Republic in the WECAFC/83/6, inasmuch as the right hand side of the parabola is defined by one point only. Hence, the estimate of maximum yield is critically dependent on the quality of the data used to derive that single point estimate.

Munro (1984) — Munro notes that an appropriate measure of fish productivity in reef environments is metric tons per km2 per year. Early in his paper, he states that a yield of 4-6 $t/km^2/yr$ may be expected in coralline shelf areas with moderately heavy exploitation. The maximum harvest that can be sustained might be 10-20 $t/km^2/yr$.

Munro included an analysis of data of Wass (1982) who had information on reef area within the 8 m isobath and the annual catch of fish within this zone for the subsistence and artisanal fisheries of American Samoa. The fish component of the catch was 16 $t/km^2/yr$, a value which Munro notes was considerably higher than Caribbean values (presumably referring to the Munro and Thompson (1973) study), but consistent with other Pacific studies. He further suggests that the differences may be due to depth distributions within the reefs, with the Pacific reefs being shallower and presumably more productive. However, it would seem that the basis of this comparison is somewhat questionable, since it is not clear to which Caribbean studies he is referring.

Munro applied his variation of the surplus production model to the data of Wass, and concluded that the potential yield from this ecosystem (fish only) was 20 $t/km^2/yr$. He notes that the value is high compared with other studies, and comments that this may be due to either "hyperproductivity" of shallow reef systems, or to a systematic bias in the data.

Galzin (1987) — This paper is one of only a few examples of attempts to calculate fish yields on an analytical basis other that that of surplus production modeling. The author focuses on the three dominant members of a fringing reef community in French Polynesia, which comprised 74% of the total fish biomass. Galzin calculated yield from the formula of Gulland (1983) as follows:

$$Y_{max} = X\,(Y + M\ \bar{B})$$

where: Y_{max} is the maximum yield, X is an arbitrary factor set at 0.3, Y is the current annual catch in 10's of $tons/km^2$, and $\bar{B}$ is the mean biomass.

Galzin concluded that the fringing reef had a maximum potential yield of 23 $t/km^2/yr$. Since the estimate was based on three species only, he noted that it was likely an underestimate.

Haughton (1988) — Haughton reexamined the Jamaica fisheries example of Munro and Thompson (1973) and concluded that the maximum yield is 2.2 $t/km^2/yr$, rather than 4.1 $t/km^2/yr$ as reported by Munro and Thompson. The general analytical model employed by Haughton was the same as that of Munro and Thompson. Haughton criticized the earlier work on the grounds that certain data were excluded from the analyses, and questioned the assumption that mechanized and unmechanized canoes represent equivalent units of fishing effort. Finally, Haughton questioned the assumption that fishermen from a given district only fish adjacent waters, particularly with the general availability of motorized crafts.

Descriptive or Data-based Approaches to Estimating Fish Yield

Stevenson and Marshall (1974) — Stevenson and Marshall presented data for selected reef fisheries. Of the eight studies reviewed by them, six were from the Caribbean region, hence their review is of particular relevance. They considered six fisheries to be low effort at the time of the study (Bermuda, Cuba and Lamotrek) and four to be high effort (Jamaica, the Virgin Islands, Mauritius and Puerto Rico). Besides being of interest because of the Caribbean focus of their work, they also reviewed papers which were relatively old. Both these considerations are important, because as shown in Figure 1, there is a tendancy for newer papers to report higher values of fish productivity than did older literature. However, this time trend is confounded by the fact that most of the later studies addressed the situation on Pacific reefs. The difference in productivity between the Caribbean and Pacific could be explained by real differences in productivity, or perhaps the emergence of a new school of thinking on this subject. We return to this point later. Stevenson and Marshall concluded that the average yield per unit area for a more developed inshore reef fishery may lie between 2.0 and 5.0 $t/km^2/yr$.

Marten and Polovina (1982) — Marten and Polovina took an approach which entailed examination of the relationships between environmental variables such as primary productivity and mean depth and potential yield for a variety of aquatic ecosystems. They elected to focus on primary productivity among indicators of potential yield because of its direct relationship to fish yield. They presented data on the primary productivity and fish yield from a variety of tropical demersal fisheries, which are shown in Figure 2. They further noted the caveat that estimates of primary productivity are often imprecise because of spatial and seasonal variation.

The data in Figure 2 do not form a significant linear regression ($p = 0.3129$). However, when the range of primary productivity values found in the Caribbean (100-150 g $C/m^2/yr$, Gulland 1971) are superimposed on the data, they are consistent with fish yields ranging from about 1 to 7 $t/km^2/yr$. However, it should be noted that the data used were not from reef fisheries, rather they were from demersal tropical fisheries. However, this paper is the only one which we are aware of which attempted to develop a predictive regression model using environmental data such as primary productivity or mean depth.

White and Savina (1987) — White and Savina employed a census approach to determining reef fish production off Apo Island, Philippines. They combined the total weight of fish counted daily for one year by middlemen/volunteers living on the island, with fish employed for local consumption, dried fish production, to arrive at an estimate of 33.8 + 6.1 $t/km^2/yr$. Their approach is

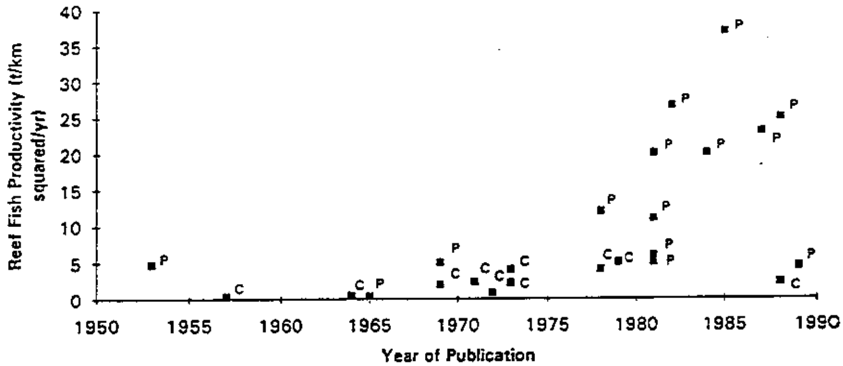

Figure 1. Potential yield of reef fisheries versus year in which the study was published. Points marked by 'C' and 'P' denote investigations in the Caribbean and Pacific, respectively.

novel since it involves a census approach. An earlier study of the same site (Alcala and Luchavez 1981) yielded a lower estimate of reef fish productivity (16.8 t/km^2/yr). Further, they note that the estimate of total reef catch is conservative, due to the non-inclusion of species discarded by fishermen. These workers also included carangids in the definition of reef fish.

Bellwood (1988) — The study site in this instance was again Apo Island, and employed a similar approach to White and Savina (1987). Bellwood, however, provided the refinement of estimates of fish yields grouped by family and by degree of reef association. Bellwood found that despite the large (38) number of families represented in the landings, they were dominated largely by the Carangidae and Acanthuridae. Bellwood arrived at a value of 24.86 + 12.75 t/km^2/yr for reef fish production, but made no attempt to reconcile this with the study of White and Savina (1987).

Acosta and Recksiek (1989) — These authors determined the total catch in an 11 km^2 intensively fished coralline shelf area in the Phillippines. Acosta and Recksiek employed a logbook system to obtain information on total fishing effort by recording the number of boats fishing each day and total traps per boat. The

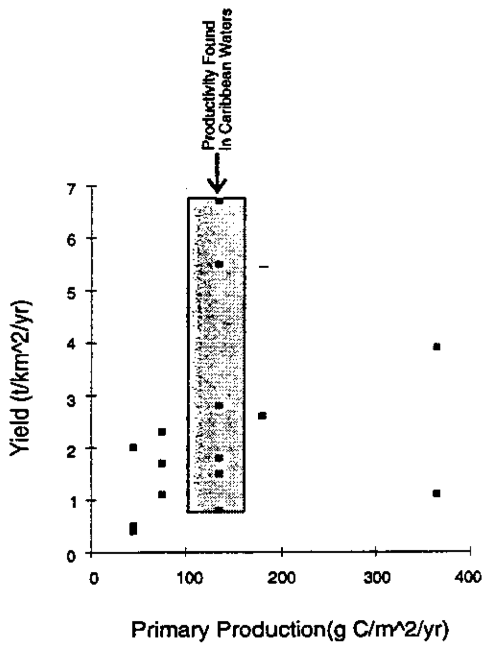

Figure 2. Primary productivity of various tropical ecosystems versus the yield of demersal fish (revised from Marten and Polovina 1982) The range of primary productivities found in the Caribbean region (Gulland 1971) is depicted by the shaded rectangle.

total catch was obtained from fishermen maintaining logs and also by informally questioning other fishermen. Catch information was also obtained through purchases in the field by the researchers. At such intervals, effort data were also collected. Monthly estimates of total catch were obtained by multiplying total effort by the monthly estimates of catch per unit of effort. The estimated annual yield for the study area was 4.4 t/km^2/yr. While this estimate was considerably lower than others from the Pacific, they noted that their estimates excluded catches by blasting and gleaning, with the latter aspect being of particular consequence.

SYNTHESIS OF LITERATURE REVIEW

We summarize available estimates of yield of reef fisheries from the Pacific and Caribbean, in Table 1 and 2 respectively. In general, estimates of yield from the Pacific are considerably higher than those from the Caribbean. Also shown in

Table 1. Estimates of yield of reef fishes from the Pacific; a – Philippines; b – cited in Marshall (1980); c – cited in Munro (1984); d – cited in Russ (1991); mean of yield estimates = 11.5; one standard error = 1.9.

Authors	Location	Yield Est.	Area (km^2)	How Obtained	Comments
Alkire (1965)	Lamotrek Atoll	0.4			
Galzin (1987)	Moorea, French Polynesia	23.0-		Ymax=X(Y+MB) Gulland 1983	fringing reef, calculation based on 3 species, underestimate?
Alcala (1981)[a]	Sumilon Id	16.5	1		averageof five years
Alcala & Luchavez (1981)[a]	Apo Island	11.4	2		non-reef areas were excluded
	Hulao-hulao Reef	5.0			intensively fished area
	Selinog Id	5.9	1		intensively fished area
Alcala & Gomez (1985)[a]	Hulao-hulao Reef	5.2	1		
	Selinog Id	6.0			
Douglas (1969)	Ifaluk	5.0			
Bayliss-Smith[b]	Fiji	4.4		abundance estimates	patchy abundance estimates
Wheeler & Ommanney (1953)	Mauritius	4.7	350		
Hill (1978)[b]	American Samoa	8.0			
Acosta & Recksiek (1989)[a]	Cape Bolinao	4.4	11	catch & effort data	intensively fished area, did not include blasting catches
Alala & Gomez	central Philippines	36.9			
Wass (1982)	American Samoa	18.3	3		
Marriott[c]	Tarawa Atoll	4.4			
Munro (1984)	American Samoa	18.3	3	data of Wass (1982)	suggests findings may be general
Wright & Richards (1985)	Tigak Ids, Papua NG	0.42	208		
Lock (1986)	Port Moresby, NG	5			
Savina & White (1986)[a]	Apo Id	10.7	2		
	Pamilacan Id	24.9	1		
Bellwood (1988)[a]	Apo Id	24.9	1		
Alcala & Russ (1990)[a]	Sumilon Id	28.4	1	average of two years	
Zann *et al* (in prep)[d]	Upolu Id, W. Samoa	11.4	300		
Ardill (1983)	Indopacific region	5.0	358572		

Table 2. Estimates of potential yield of reef fishes from the Caribbean.

Authors	Location	Yield Est.	Area (km^2)	How Obtained
Bardach & Menzel	Bermuda	0.4	1035	
Munro (1969)	Jamaica	2.0		
Munro & Thompson (1973)	Jamaica	4.1		
Juhl & Suarez-Caabro (1972)	Puerto Rico	0.8	2300	
Buesa Mas (1964)	Cuba	0.5	55000	
Haughton (1988)	Jamaica	2.2	4170	yield vs. fishing effort plots
Gulland (1971)	Bahamas	2.4		
WECAFC (1983)	Dominican Republic	2.5		Munro spatial surplus production model
Koslow et al. (submitted)	Jamaica/Belize	1.9	2515	Munro's approach with geographically disparate areas
Higgs (1983)	Bahamas	1.4	116549	area valua from CFMC (1985)
Olson (1984)	St Kitts/Nevis	2.1	708	
Juhl (1973)	Puerto Rico & USVI	3.3	7504	
Average Yield		2.0		
One Standard Error		0.3		

the Tables are the mean values of reef fish production for the two regions, along with an indication of variability (± one standard error). Since the estimates of yield of reef fisheries differ so much between the Pacific and the Caribbean, we elected to use the Caribbean literature only to derive our estimate of probable fish yield in the region.

DISCUSSION

Based on the information presented in Table 2, we conclude that the range of potential yields possible from reef fisheries on coralline shelves of the Caribbean is 1.7 -2.3 $t/km^2/yr$. To compare that estimate of potential yield to actual removals, we present time series of landings for selected Caribbean countries in relation to the estimate of yield for the shelf area (Figure 3). Only those countries which had landings data disaggregated by family or more precisely were used to construct our examples. With the exception of Jamaica (Figure 3D), landings were considerably less than the potential yield. The striking discrepancies between potential yield and actual landings could be due to either over- or under exploitation. While this review does not provide information on the level of exploitation, there are many published reports for fisheries throughout the Caribbean region which have suggested demersal stocks are overexploited (Mahon 1987, Koslow *et al.* 1988). The discrepancy between removals and potential yield may also be due to incomplete reporting. Data collection systems in Caribbean fisheries are either non-existent or relatively new (Mahon 1991) , and national coverage may be limited to major landing sites only. In such instances, national landings will be underestimated. Such biases, however, seem unlikely to completely account for the differences between potential and actual yield.

Jamaica has repeatedly been cited as a clear example of overfishing in the Caribbean region (see, for example, Koslow *et al.* 1988). The smaller discrepancy between actual landings and potential yield in Jamaica shown on Figure 3D. appears inconsistent with this view, on first examination. However, we argue that while the Jamaican fishery has been able to maintain high levels of total landings, it has been able to do so only by shifting exploitation to more productive, smaller, herbivorous species of the reef fish community. Further comparison of the species composition of landings among Caribbean countries could confirm this view.

Our estimate of the range of potential yields from Caribbean fisheries is conservative relative to some others. For example, Munro (1984) concluded that 4 to 6 $t/km^2/yr$ seems a valid generalization of potential yield from coralline shelf under heavy exploitation. Mahon (1990) included a broader range of yield estimates among the scenarios possible for Caribbean fisheries (0.5 to 5.0 $t/km^2/yr$). Although not really comparable for the reasons given previously, our estimate of potential yield is also conservative with regard to the data of Marten

Table 3. Examples of lost income resulting from current patterns of exploitation.

	Most Recent Annual Landings (t, reef-associated species only)	Lower Limit of Potential Yield (from Fig. 3)	Value of Landings Not Realized with Current Pattern of Exploitation ($EC)
Grenada	251	2712	9,844,000
St. Lucia	17	887	3,482,800

and Polivina shown in Figure 2, for the range of values of primary productivity typically found in the Caribbean.

We have noted a time trend in estimates of productivity, with more recent studies indicating higher levels of productivity than those prior to 1975 (Figure 1). Such a pattern could be explained by a change in researchers' perceptions of fish yield over a long period of time. However, we believe that a more convincing explanation is that the majority of Pacific investigations were completed after 1980, thus causing the apparent time trend in the reported results.

The differences in productivity between Caribbean and Pacific reef fisheries (Tables 1 and 2, Figure 1) warrant further consideration. We suggest that the difference in average productivity between the Pacific and Caribbean regions in the literature reviewed here may be artifactual. As shown in Figure 3, there is a relationship between size of the study area and apparent potential yield, with larger study sites being associated with smaller yields. Furthermore, as indicated in Tables 1 and 2, a larger proportion of studies in the Pacific dealt with a reef-specific study area. It may be that with more precise information on the extent of live coral reef in the Caribbean, more precise estimates of yields of fish could be forthcoming. This point has also been explored recently by Arias-Gonzales *et al.* (1994).

Longhurst and Pauly (1987) note that when comparing species richness of tropical reef communities around the world, coral reefs in the western Indo-Pacific support the most diverse fish communities, with the greatest diversity occurring in the Philippines, while the least diverse are in the Atlantic. Sale (1980) shows that the numbers of species of fish in regional reef faunas ranges from more than 2,000 in the Philippines to less than 200 in the northern Caribbean. However, while it is readily demonstrated that the Pacific has a more diverse tropical fish fauna than does the Caribbean, there is no indication that such differences in diversity are accompanied by greater average total fish production.

Even within the Pacific or Caribbean regions, there are striking differences in potential yield. What factors might be responsible for such variation? Marten

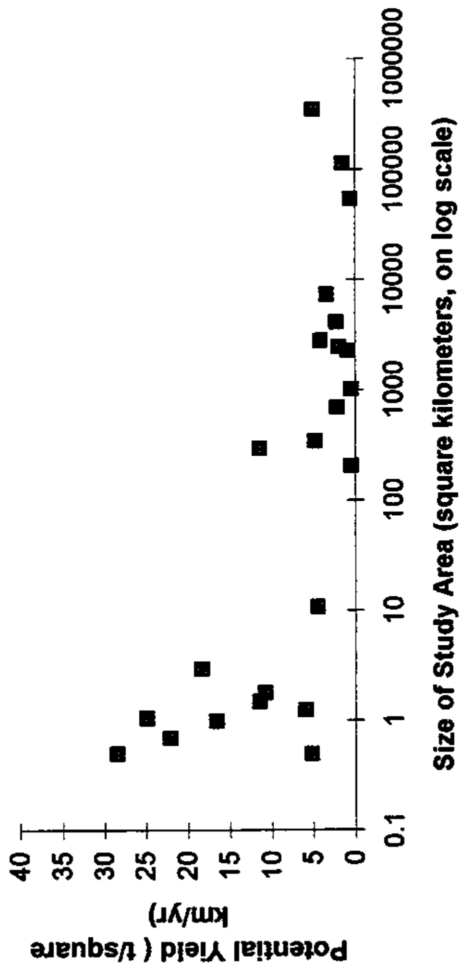

Figure 3. The relationship between study size area and the estimate of potential yield for the fisheries reviewed here.

and Polovina (1982) have suggested that factors such mean depth or primary productivity account for apparent differences in yield among ecosystems. The physiography of the reef and its structural complexity may be another important factor. More structurally diverse reefs may offer a greater number and variety of niches for fish to occupy. Differences in potential yield may also be artifacts of the method of investigation. For example, Bellwood (1988) advised workers to carefully define what they mean by "reef fish yield", a point also made by Galzin (1984). From this literature review, it is clear that the definition of reef yields does vary substantially. In fact, as Bellwood (1988) further notes, some of the species included in the reef catches may have little or no relation to the reef area included in the calculations. Some of the smaller planktivores which occupy reef habitat opportunistically are examples of such species. Bellwood also notes that the definition of reef area is critical. In the Apo Island study site of Bellwood, he demonstrated how fish yield could vary from 48.8 to 24 $t/km^2/yr$, contingent on whether the 20 or 60-m isobath was used to define the extent of the reef.

This review has discussed two approaches for determining potential yield of reef fisheries. The first, based on analytical models such as variants of the surplus yield approach, is generally most applicable for larger geographic areas. The second approach, which is largely empirical, entails the collection of biological data through a sample or census approach in studies which are usually small, well-defined, even reef-specific. However, it is important to realize that if previous landings are to be considered estimates of maximum yield, the level of exploitation which yielded those catches must correspond to the MSY (Maximum Sustainable Yield) level and the fishery must be in equilibrium. Therefore, if overfishing is the rule in unregulated systems, estimates of potential yield based on landings information may be misleading at best.

Regardless of the general approach for estimation of potential yield, controversy remains regarding the accuracy and precision of estimates of productivity from reef fisheries. However, comparison of actual landings in Caribbean fisheries to a conservative range of potential yield estimates indicate that management of fisheries resources could be significantly improved, and better serve the needs of the region.

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