8681

AN APPROACH TO YIELD ASSESSMENT FOR UNEXPLOITED RESOURCES WITH APPLICATION TO THE DEEP SLOPE FISHES OF THE MARIANAS

JEFFREY J. POLOVINA AND STEPHEN RALSTON[1]

ABSTRACT

A comprehensive approach to estimate the maximum sustainable yield (MSY) for a tropical multispecies resource which lacks catch and effort data is presented. This yield assessment approach was used to design a fishery resource assessment survey of the Mariana Archipelago. An application of the method is presented to estimate the MSY for a multispecies bottom fish resource, based on data collected during the survey. The annual MSY for the deep slope fishes (primarily snappers and groupers) of the Mariana Archipelago is estimated to be 109 t, which for comparative purposes is equivalent to 222 kg/nmi of 200 m isobath or 0.3 t/km^2.

Assessment of tropical resources has always created major problems in fisheries research (Saila and Roedel 1979; Pauly and Murphy 1982). This has been largely due to three factors: technical difficulties in aging, a high species diversity in tropical communities, and what is typically a multiplicity of artisanal gears used in these fisheries. The latter problem has been especially difficult to surmount, making it difficult to determine not only the level of fishing effort but sometimes even the total catch. Without these data many standard fisheries techniques such as stock-production methods are inapplicable (but see Csirke and Caddy 1983).

In recent years, however, new methods and modifications of existing methods have been proposed to estimate growth and mortality parameters, standing crop, and yield for fish stocks in the absence of a time series of commercial catch and effort data (Beddington and Cooke 1983; Pauly 1983; Polovina 1986a; Wetherall et al. in press). We will show that several of these techniques can be combined, producing an integrated approach to yield assessment designed specifically for tropical fisheries resources in situations where catch and effort data are lacking. The approach is then applied to data gathered in a fishery survey of the Mariana Archipelago to estimate maximum sustainable yield (MSY) for a multispecies resource of deep slope snappers and groupers.

[1]Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, HI 96822-2396.

Manuscript accepted February 1986.
FISHERY BULLETIN: VOL. 84, NO. 4, 1986.

YIELD ASSESSMENT

The equilibrium yield assessment is presented schematically in Figure 1. This approach assumes that growth follows the deterministic von Bertalanffy curve with parameters K and L_∞, that the mortality of fish above the smallest length fully represented in the catch (L_c) occurs at a constant instantaneous rate (Z), and that recruitment is constant with R recruits entering the first vulnerable age class annually. It is also assumed that the resource is essentially pristine, such that an estimate of the biomass recruited to the fishery in the absence of exploitation (B_∞) can be obtained from a catch-per-unit-effort (CPUE) survey and an estimate of catchability. In the discussion section, the effect of relaxing some of these assumptions will be considered.

For each species under consideration, the data required for this program, at a minimum, consist of a large length-frequency sample, otolith data and/or a time series of length-frequency data, a systematic CPUE survey, and an estimate of catchability, such as that obtained from an intensive fishing experiment. The large length-frequency sample is used to jointly estimate the asymptotic length (L_∞) and the ratio of total instantaneous mortality (Z) to the von Bertalanffy growth parameter (K) based on the following relationship:

$$\Theta = Z/K = (L_\infty - \bar{l})/(\bar{l} - L_c),$$

where L_c is a parameter defined above and $\bar{l}$ is the mean length of all fish greater than L_c (Beverton

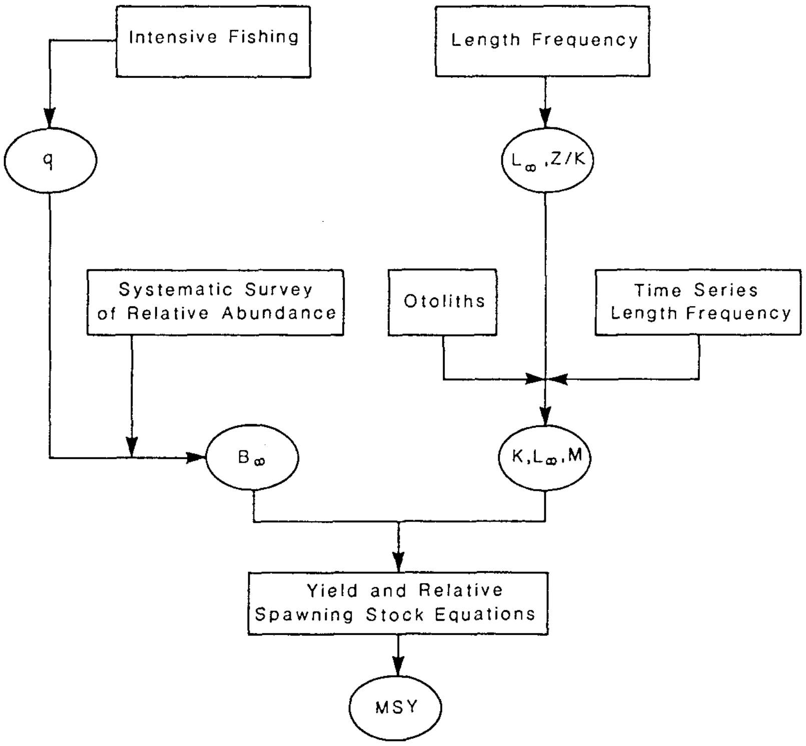

FIGURE 1.—Schematic of the yield assessment approach. A more general approach to fishery assessment which includes a treatment of catch and effort data as well is given in Munro (1983); our Figure 1 represents a detailed subset of Munro's figure 1 (1983).

and Holt 1956). For a series of L_c values at intervals beginning with the smallest L_c and going up to L_∞, there will be a corresponding set of $\bar{l}$ values. By solving the Z/K equation above for $\bar{l}$ as a function of L_c, the following relationship is obtained:

$$\bar{l} = L_\infty/(\Theta + 1) + L_c\,(\Theta/(\Theta + 1)).$$

Thus, regressing a sequence of $\bar{l}$ values on the corresponding L_c values will produce estimates for the slope and intercept which can be solved for estimates of L_∞ and Z/K (Wetherall et al. in press).

Once an estimate of L_∞ has been obtained by this method, otolith data and/or a time series of length-frequency data can be fit to the von Bertalanffy growth curve to estimate the growth coefficient K. Estimation of L_∞ from length-frequency data was used for the Marianas bottom fish data because a large length-frequency sample was available and otolith readings were difficult to interpret for old stages of growth. With an estimate for K, the total mortality rate, Z, can then be estimated as the product of K and the ratio of Z/K obtained in the previous step. Alternatively, one can estimate Z from a catch curve constructed from a length-frequency sample which has been corrected for nonlinear growth and converted to an age-frequency sample (Pauly 1983).

If these techniques are applied to unexploited or lightly exploited resources, the estimate of Z provides an estimate of the instantaneous rate of natural mortality (M). However, if fishing mortality is believed significant, an equation to estimate M as a function of K, L_∞, and mean annual water temperature (T) (in °C) has been developed as follows (Pauly 1983):

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T.$$

Given estimates of K, M, and age of entry to the fishery (t_c), the Beverton and Holt (1957) yield per recruit (Y/R) equation can be used to compute the ratio of equilibrium yield to unexploited recruited biomass as a function of fishing mortality (F). The equilibrium yield (Y) can be expressed as

$$Y = R\,F \int_{t_c}^{\infty} \exp\,(-tM - (t - t_c)\,F)\; w(t)\; dt,$$

where $w(t) = W_\infty\,(1 - \exp(-Kt))^b$, and where W_∞ is the asymptotic weight and b is the exponent of the length-weight relationship. The unexploited recruited biomass (B_∞) can be expressed as

$$B_\infty = R \int_{t_c}^{\infty} w(t)\,\exp(-Mt)\; dt.$$

The ratio of equilibrium yield to unexploited recruited biomass (Y/B_∞) is then independent of W_∞ and R, depending only on K, M, t_c, F, and b. Tables and computational formulae are readily available to evaluate these integrals for Y and B_∞ as functions of t_c and F (Beverton and Holt 1966; Beddington and Cooke 1983). Upon estimation of B_∞, the equilibrium yield is estimated for a given level of F as the product of Y/B_∞ and B_∞.

If a stock is unfished, B_∞ can be estimated by mapping the relative abundance of the stock in terms of CPUE from a systematic survey and then converting estimates of relative abundance into biomass with an estimate of catchability. There are a number of methods which have been used to estimate catchability (Ricker 1975). For work on Pacific island fishery resources, an intensive fishing approach, which fishes a small isolated location heavily and regresses CPUE on cumulative catch (Leslie model), has been used successfully to estimate catchability for bottom fishes and shrimp (Polovina 1986a; Ralston 1986). If only one estimate of catchability is obtained, then the standing stock per unit of area is determined as the ratio of CPUE to catchability in the appropriate units of weight or numbers. If several estimates of catchability are available corresponding to different levels of CPUE, then it might be appropriate to fit a more general power function relationship between CPUE and standing stock (Bannerot and Austin 1983).

The product of Y/B_∞ and B_∞ as a function of F is the equilibrium yield based on the assumption of constant recruitment. While this assumption will be valid for low levels of exploitation, there will come a point as F increases that recruitment will begin to decline and sustainable yield may thus be less than the yield predicted under the assumption of constant recruitment. Estimating MSY yield as the maximum equilibrium yield obtained over all F from the product of Y/B_∞ and B_∞ may, therefore, overestimate the actual MSY. There are two adjustments which have been proposed to estimate MSY in the absence of detailed knowledge of the spawner-recruit relationship. One approach is to estimate MSY from the constant recruitment yield curve as that yield corresponding to that level of F where the addition of one unit of mortality increases the yield by 10% of the amount caught by the first unit of F (Gulland 1983, 1984). This level of mortality and corresponding yield have been denoted as $F_{0.1}$ and $Y_{0.1}$, respectively. A second approach to estimating MSY from the constant recruitment yield curve is to use the Beverton and Holt equation to calculate the ratio of the spawning stock biomass under exploitation (S) to the spawning stock biomass in the absence of exploitation (S_0) and to use this ratio as an indicator of the sustainability of a yield for a given combination of F and t_c. For simplicity, we assume that the age of sexual maturity (t_m) is identical for both sexes. Then the unexploited spawning stock biomass (S_0) is

$$S_0 = R \int_{t_m}^{\infty} \exp(-Mt)\; w(t)\; dt,$$

and

$$S = R \int_{t_m}^{\infty} \exp(-Mt - (t - t_c)\,F)\; w(t)\; dt.$$

Thus, the ratio of S/S_0 depends only on M, K, t_c, t_m, and F.

It has been suggested that the spawning stock biomass of a species should not be reduced below 20% of its unexploited level if a substantial reduction in the recruitment is to be avoided (Beddington and Cooke 1983). Thus, the estimate of MSY is determined as the maximum yield from the constant recruitment curve subject to the constraint that F does not exceed the level which reduces the relative spawning stock biomass below 0.20 of S_0.

ASSESSMENT OF SNAPPERS AND GROUPERS IN THE MARIANAS

The Mariana Archipelago consists of a chain of islands and banks on a north-south axis beginning with Galvez Banks and Santa Rosa Reef at the southern end and extending northward to Farallon de Pajaros (30 nmi north of Maug Island). A chain of seamounts also runs on a north-south axis about 120 nmi west of the high island chain (Fig. 2).

Six resource assessment cruises of 40 d each were conducted in the Marianas during the period from May 1982 through June 1984. During these cruises, the deepwater snapper and grouper community along the outer slope was sampled at all 22 islands and banks labeled in Figure 2. Thirteen of these 22 sampling sites were visited at least once during the first three cruises and, again, during the second set

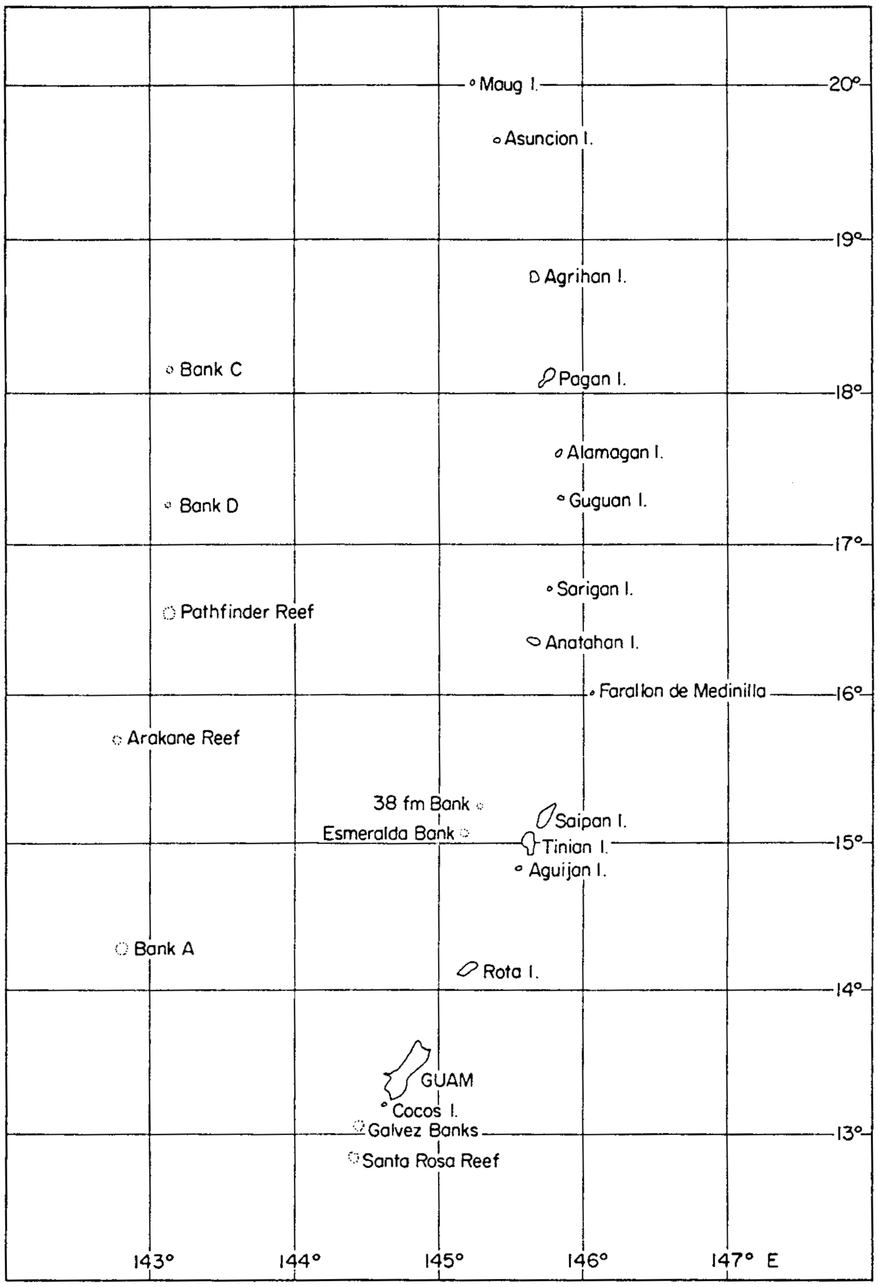

FIGURE 2.—The Mariana Archipelago with the 22 islands and banks sampled.

of three cruises. Two sites, Pagan Island and Esmeralda Bank, were sampled on each of the six cruises to establish a time series of length-frequency data.

The NOAA ship *Townsend Cromwell* was used as the fishing vessel for all the cruises. The fishing was conducted from four hydraulic gurdies equipped with 365 m of braided 90 kg Dacron[2] line. The terminal rig consisted of four hooks spaced about 1 m apart and of 2 kg weight.

At each island and bank, an attempt was made to perform a systematic fishing survey of the bottom fish community along the 200 m contour. Fishing was conducted while the vessel drifted and targeted the 125-275 m depth range. Fishing effort was measured in line-hours, defined as the product of the number of lines fished with the length of time, in hours, that they are fished.

Seven species—one jack, *Caranx lugubris*, and six snappers, *Pristipomoides zonatus*, *P. auricilla*, *P. filamentosus*, *P. flavipinnis*, *Etelis carbunculus*, and *E. coruscans*—accounted for about 92% of the catch (Polovina 1986b). Large length-frequency samples were collected for all seven species, primarily from the unfished islands and banks, and were used to jointly estimate M/K, the ratio of instantaneous natural mortality (M) to the growth parameter of the von Bertalanffy growth curve (K), and the asymptotic length (L_∞) by regressing a sequence of mean lengths on minimum lengths (Wetherall et al. in press). Otoliths were collected for all seven species and the growth coefficient K was estimated by fitting a von Bertalanffy growth curve to otolith data with L_∞ fixed at the value estimated from the length-frequency analysis (Ralston and Williams[3]). Once K and the ratio of M/K were estimated, an estimate of M was obtained from their product. The size of entry to the fishery was estimated as the integrated midpoint of the ascending limb of the size-frequency distribution (Gulland 1969). This size was then converted to an age of entry into the fishery (t_c) by application of the von Bertalanffy growth curve. The values of L_∞, K, M, t_m, and t_c for the seven species which are required by the yield analysis are given in Table 1. The exponent of the length-weight equation (b) for most of the species is not significantly different from 3.0, so to simplify the computation, it will be taken as 3.0 for all the species (Ralston in press).

An estimate of the catchability of the bottom fishes which was used to convert CPUE into standing stock was derived from an intensive fishing experiment conducted at Pathfinder Reef (Polovina 1986a). Thirteen days of intensive handline fishing with the *Townsend Cromwell* at Pathfinder Reef produced a substantial and significant decline in CPUE. Application of the Leslie model (Ricker 1975), which regresses CPUE against cumulative catch, produced estimates of catchability for three species—*Pristipomoides zonatus*, *P. auricilla*, and *Etelis carbunculus* (Polovina 1986a). While interesting differences in catchability among species were found, the estimate of the total unexploited biomass for the three species obtained from the species specific Leslie model was not significantly different from the total unexploited biomass computed from the Leslie model applied to the catch and CPUE data pooled over all three species. Catchability from the pooled Leslie model is estimated to be 0.0066 nmi/line-hour. This value was used as an estimate of total

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[3]Ralston, S., and H. A. Williams. Age, growth, and mortality of deep slope lutjanid fishes from the Mariana Archipelago. Manuscr. in prep. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396.

TABLE 1.—Population parameters for the seven major species caught by handlining in the Marianas.

Species	Von Bertalanffy growth parameters L_∞ (cm)	K (1/yr)	Instantaneous natural mortality (M)	Age of entry to the catch t_c (yr)	Age of maturity t_m (yr)
Caranx lugubris	75.1	0.430	0.53	1.3	1.8
Pristipomoides filamentosus	67.3	0.228	0.57	4.3	2.0
P. auricilla	42.6	0.335	0.81	3.6	2.4
P. flavipinnis	54.1	0.238	1.12	3.7	2.2
P. zonatus	47.0	0.245	0.63	4.65	3.25
Etelis coruscans	97.6	0.166	0.38	6.2	4.1
E. carbunculus	69.1	0.175	1.55	3.45	2.75

bottom fish catchability and was used to estimate standing stock from CPUE.

The systematic survey of relative abundance uses the fishing drift as the basic sampling unit. A drift is defined as the fishing which occurs during an uninterrupted drift by the vessel while fishing continuously in the 125-275 m depth range. The CPUE measured is the number of fish per line-hour and can be computed in two ways for each bank. Bank CPUE will be defined as the total number of fish caught at an island or bank divided by the total number of line-hours fished. Bank mean drift CPUE or simply mean drift CPUE will be defined as the mean of all the individual drift CPUE values for a bank, where the drift CPUE is computed as the number of fish caught within a drift divided by the drift line-hours. While the two measures of CPUE are highly correlated, they are not identical. In our analysis the mean drift CPUE was used as a measure of relative abundance because in a systematic survey the drifts within a bank can be thought of as replicates drawn from the total bank population allowing estimation of within bank variation in CPUE. For a bank, the total standing stock or number of exploitable bottom fishes (N) can be calculated from CPUE, the length (L) of the 200 m contour, and the catchability (q) expressed per nautical mile of 200 m contour as follows:

$$N = (\text{CPUE})\ (L/q).$$

The values of N, CPUE, and L for the banks sampled are given in Table 2.

The catch at any bank can be grouped into eight groups—the seven major species defined previously, plus a group called "others" for all other species. The fraction of the catch (by number) of the total bank catch as determined from fishing surveys, is given in Table 3. The mean weight of each species caught at each site is given in Table 4. For each bank, the unexploited recruited biomass (B_∞) for each of the eight groups is estimated by partitioning the total standing stock into a standing stock for each species group from Tables 2 and 3 and then converting the standing stock for each species group into biomass for each group based on the mean weights in Table 4. Estimates of B_∞ for the eight species groups at each bank are given in Table 5 and the total unexploited biomass is given in Table 6. The estimates of biomass per nautical mile of 200 m contour at Saipan, Tinian, Rota, and Guam are less than half the levels at most other banks. These four islands are the only islands in the Marianas with a substantial resident population. The local fishermen at these islands are known to exploit the bottom fish stocks locally so that estimates of biomass based on bank CPUE values are likely to underestimate unexploited levels. The mean of the biomass per nautical mile of 200 m contour for the two uninhabited islands and one bank in the southern islands is 600 kg. This value was used for unex-

TABLE 2.—Mean drift catch per unit effort (CPUE) and the estimated number of exploitable bottom fish recruited at each bank samples. SE indicates standard error.

Banks and islands	Mean drift CPUE (fish/ line-hour)	SE	Length of 200 m contour (nmi)	Total number of fish at each bank
Maug	5.03	1.02	10.4	7,580
Asuncion	2.16	0.49	11.1	3,480
Agrihan	4.20	0.31	18.3	11,140
Pagan	4.57	0.40	30.0	19,870
Alamagan	2.37	0.19	11.3	3,881
Guguan	3.01	0.30	9.3	4,060
Sarigan	2.82	0.37	8.5	3,470
Anatahan	2.31	0.23	17.2	5,760
Farallon de Medinilla	3.29	0.65	76.9	36,670
Saipan	1.72	0.34	52.6	13,110
38-Fathom	3.12	0.26	2.8	1,270
Tinian	1.96	0.29	28.9	8,210
Aguijan	3.84	0.98	15.9	8,850
Esmeralda	2.29	0.15	12.3	4,080
Rota	1.91	0.40	31.7	8,780
Guam	1.53	0.35	85.2	18,890
Galvez-Santa Rosa	2.95	0.31	52.5	22,450
Bank C	5.91	1.57	3.0	2,570
Bank D	5.85	0.51	3.0	2,540
Pathfinder	4.58	0.23	3.0	1,990
Arakane	3.36	0.24	2.9	1,410
Bank A	3.71	0.57	3.6	1,940

TABLE 3.—The fraction of the number of fish caught at each bank in the eight species groups.

Banks and islands	*Caranx lugubris*	*Pristipomoides filamentosus*	*P. auricilla*	*P. flavipinnis*	*P. zonatus*	*Etelis coruscans*	*E. carbunculus*	Others
Maug	0.016	0.000	0.347	0.016	0.425	0.000	0.102	0.094
Asuncion	0.036	0.036	0.089	0.000	0.589	0.018	0.036	0.196
Agrihan	0.016	0.041	0.103	0.064	0.602	0.016	0.110	0.048
Pagan	0.007	0.002	0.089	0.013	0.699	0.023	0.126	0.042
Alamagan	0.010	0.013	0.232	0.011	0.495	0.143	0.059	0.037
Guguan	0.020	0.004	0.182	0.004	0.613	0.047	0.083	0.047
Sarigan	0.016	0.010	0.141	0.010	0.646	0.042	0.057	0.078
Anatahan	0.015	0.035	0.119	0.148	0.540	0.040	0.045	0.059
38-Fathom	0.064	0.028	0.228	0.047	0.434	0.019	0.045	0.136
Esmeralda	0.017	0.051	0.040	0.366	0.397	0.029	0.026	0.074
Farallon de Medinilla	0.052	0.021	0.093	0.166	0.477	0.021	0.093	0.078
Saipan	0.013	0.138	0.087	0.338	0.225	0.000	0.075	0.125
Tinian	0.000	0.000	0.083	0.694	0.000	0.056	0.139	0.028
Aguijan	0.021	0.188	0.063	0.417	0.271	0.000	0.000	0.042
Rota	0.019	0.143	0.162	0.114	0.362	0.029	0.067	0.105
Guam	0.064	0.161	0.258	0.129	0.161	0.000	0.129	0.097
Galvez-Santa Rosa	0.085	0.017	0.364	0.051	0.322	0.009	0.059	0.093
Bank C	0.000	0.017	0.390	0.000	0.356	0.017	0.212	0.009
Bank D	0.015	0.010	0.091	0.005	0.480	0.045	0.349	0.005
Pathfinder	0.059	0.011	0.172	0.004	0.506	0.000	0.215	0.032
Arakane	0.116	0.057	0.188	0.003	0.412	0.000	0.169	0.055
Bank A	0.008	0.004	0.184	0.008	0.607	0.000	0.159	0.029

TABLE 4.—Mean weight (kg) of the fish caught by bank and species group.

Banks and islands	*Caranx lugubris*	*Pristipomoides filamentosus*	*P. auricilla*	*P. flavipinnis*	*P. zonatus*	*Etelis coruscans*	*E. carbunculus*	Others
Maug	3.784	1.930	0.815	1.585	0.977	6.113	0.893	2.559
Asuncion	3.784	1.930	0.848	1.265	1.344	6.113	0.670	4.595
Agrihan	3.784	1.930	0.784	1.235	1.169	6.113	0.741	7.787
Pagan	3.784	1.930	0.651	1.169	1.094	6.113	0.652	5.068
Alamagan	3.784	1.930	0.834	1.354	1.326	6.113	1.010	2.992
Guguan	3.784	1.930	0.773	1.780	1.216	6.113	0.815	2.400
Sarigan	3.784	1.930	0.642	1.025	1.204	6.113	0.811	5.279
Anatahan	3.784	1.930	0.556	1.169	0.874	6.113	0.586	2.631
38-Fathom	3.784	1.930	0.532	1.193	0.874	6.113	0.798	2.523
Esmeralda	3.784	1.930	0.567	1.014	0.782	6.113	0.702	8.409
Farallon de Medinilla	3.784	1.930	0.439	1.265	0.891	6.113	0.575	1.963
Saipan	3.784	1.930	0.577	0.992	0.837	6.113	0.773	1.353
Tinian	3.784	1.930	0.653	1.003	1.017	6.113	0.422	0.520
Aguijan	3.784	1.930	0.480	0.927	0.760	6.113	0.753	0.770
Rota	3.784	1.930	0.542	1.222	0.667	6.113	0.506	3.168
Guam	3.784	1.930	0.606	1.112	0.780	6.113	0.673	0.600
Galvez-Santa Rosa	3.784	1.930	0.522	1.206	0.979	6.113	0.801	2.085
Bank C	3.784	1.930	0.761	1.265	1.267	6.113	0.923	0.920
Bank D	3.784	1.930	0.961	1.710	1.169	6.113	0.983	1.070
Pathfinder	3.784	1.930	1.953	1.381	1.218	6.113	0.875	7.348
Arakane	3.784	1.930	0.860	1.350	0.949	6.113	0.791	2.338
Bank A	3.784	1.930	0.636	1.605	0.984	6.113	0.811	5.504

TABLE 5.—The unexploited recruited biomass by bank for each species groups in metric tons.

Banks and islands	*Caranx lugubris*	*Pristipomoides filamentosus*	*P. auricilla*	*P. flavipinnis*	*P. zonatus*	*Etelis coruscans*	*E. carbunculus*	Others
Maug	0.5	0	2.2	0.2	3.3	0	0.7	1.9
Asuncion	0.5	0.2	0.3	0	2.9	0.4	0.1	3.3
Agrihan	0.7	0.9	0.9	0.9	8.2	1.1	0.9	4.4
Pagan	0.6	0.1	1.2	0.3	15.9	2.9	1.7	4.4
Alamagan	0.1	0.1	0.8	0.1	2.7	3.5	0.2	0.5
Guguan	0.3	<0.1	0.6	<0.1	3.2	1.2	0.3	0.5
Sarigan	0.2	0.1	0.3	<0.1	2.8	0.9	0.2	1.5
Anatahan	0.3	0.4	0.4	1.0	2.8	1.5	0.2	0.9
38-Fathom	0.3	0.1	0.2	0.1	0.5	0.2	<0.1	0.5
Esmeralda	0.3	0.4	0.1	1.6	1.3	0.7	0.1	2.7
Farallon de Medinilla	7.5	1.5	1.6	8.0	16.3	4.9	2.1	5.8
Saipan	0.6	3.6	0.7	4.6	2.6	0	0.8	2.3
Tinian	0	0	0.5	6.0	0	2.9	0.3	0.1
Aguijan	0.7	3.3	0.3	3.6	1.9	0	0	0.3
Rota	0.7	2.6	0.8	1.3	2.2	1.6	0.5	3.1
Guam	4.8	6.1	3.1	2.8	2.5	0	1.7	1.1
Galvez-Santa Rosa	7.5	0.8	4.5	1.4	7.4	1.2	1.1	4.6
Bank C	0	0.1	0.8	0	1.2	0.3	0.5	<0.1
Bank D	0.2	0.1	0.2	<0.1	1.5	0.7	0.9	<0.1
Pathfinder	0.5	<0.1	0.4	<0.1	0.3	0	0.4	0.5
Arakane	0.6	0.2	0.2	<0.1	0.6	0	0.2	0.2
Bank A	0.1	<0.1	0.2	<0.1	1.2	0	0.3	0.3
Total	32.5	32.0	24.5	43.1	85.4	26.2	15.9	42.8

TABLE 6.—The total unexploited recruited biomass (B_∞) in metric tons (t) and the total unexploited recruited biomass per nautical mile (nmi) of 200-m contour in kilograms (kg) by bank.

Banks and islands		Total unexploited recruited biomass (t)		Biomass per nmi of 200 m contour (kg)
Northern banks and islands				
Maug		8.8		850.3
Asuncion		7.7		689.7
Agrihan		18.1		991.1
Pagan		27.0		900.7
Alamagan		8.0		706.8
Guguan		6.1		659.7
Sarigan		6.1		714.0
Anatahan		7.6		440.6
38-Fathom		1.8		637.1
Esmeralda		7.2		584.1
	Total	98.4	Mean	717.4
Southern banks and islands				
Farallon de Medinilla		47.7		620.2
Saipan		15.3		290.9
Tinian		10.0		346.0
Aguijan		10.1		637.0
Rota		12.4		391.2
Guam		22.2		260.6
Galvez-Santa Rosa		28.5		542.4
	Total	146.2	Mean	441.2
Western seamounts				
Bank C		2.9		973.0
Bank D		3.6		1,207.0
Pathfinder		3.1		1,024.0
Arakane		2.0		695.9
Bank A		2.1		594.7
	Total	13.7	Mean	898.9

ploited biomass per nautical mile of 200 m contour in the subsequent yield estimation, in place of the values computed from the bank CPUE values for the inhabited southern islands (Saipan, Tinian, Rota, and Guam).

For each species group with values of K, M, t_c, and F, the ratio of fishery yield to unexploited recruited biomass (Y/B_∞) can be computed from the Beverton and Holt yield equations (Beddington and Cooke 1983). The product of Y/B_∞ with the species group unexploited recruited biomass estimates (Table 5) results in estimates of equilibrium yield for the seven species for which estimates of K and M are available. For the eighth group, which consists of all other species, the ratio of yield to B_∞ is taken as the ratio of total yield for the seven species divided by their total B_∞. For a fixed F, the sum of the equilibrium yield of the eight species groups at a bank is the bank equilibrium yield, and the sum of the equilibrium yields for a species group over all the banks is the species group equilibrium yield.

The equilibrium yield for the multispecies bottom fish complex fished with handline gear in the 125-275 m depth range for the 22 islands and banks of the Mariana Archipelago increases rapidly as a function of F to a level of about 90 t and beyond that exhibits a gradual increase with increased fishing mortality (Table 7). The MSY estimation approach estimates MSY as the yield from the constant recruitment yield curve corresponding to that level of mortality where a marginal increase in one unit of mortality increases the catch by 0.1 of the amount caught by the first unit of F. The value of $F_{0.1}$ for the bottom fish resource in the Marianas is estimated to be $F = 1.0$ and the corresponding annual equilibrium yield is 82 t (Table 7).

TABLE 7.—Total annual sustainable handline yield in metric tons (t) for a range of fishing mortalities.

Fishing mortality (F)	Total yield (t)
0.1	23
0.5	64
[1]1.0	[1]82
1.5	89
2.0	92
2.5	94

[1]$F_{0.1}$ and $Y_{0.1}$ as defined by Gulland (1983).

The equilibrium yield value of 82 t, which corresponds to a fishing mortality of 1.0, is based on the current estimated age of entry to the fishery and not necessarily the age of entry which maximizes the Y/R. For a fishery mortality of 1.0, the estimated age of entry which maximizes Y/R is computed from the Beverton and Holt equation and compared with the current age of entry for each species (Table 8). With the exception of the jack, *Caranx lugubris*, the age of entry which maximized Y/R is less than the current age of entry (Table 8). Based on the age of entry which maximized the Y/R, new levels of sustainable yield for each species group as a function of F can be computed as the product of the yield for the current age of entry with the ratio of Y/R maximized over age of entry to the Y/R for the current age of entry. The values of $F_{0.1}$ and $Y_{0.1}$ for the ages of entry which maximize the Y/R are 1.0 and 109 t, respectively (Table 9). An approximate confidence interval (C.I.) for this yield estimate can be obtained from a Taylor series expansion which incorporates the variance estimate for catchability (Polovina 1986a) and a sampling variance of the bank CPUE values (Table 2). The standard error of the yield estimate is 14 t, and thus a 95% C.I. for the yield at $F_{0.1}$ for the archipelago is 81-137 t annually.

The estimation of MSY based on the relative spawning stock approach requires estimates of the age of sexual maturity (t_m). A relationship expressing the length at sexual maturity (L_m) as a fraction of the length of the upper one percentile (L_{max}) for tropical bottom fishes is as follows (Anonymous 1977, from Brouard and Grandperrin 1984):

$$L_m = 0.576\ L_{max}.$$

TABLE 8.—Current age at entry and age at entry which maximizes the yield per recruit (Y/R) at $F = 1.0$.

Species	Current age at entry t_c (yr)	Age at entry which maximizes Y/R (yr)
Caranx lugubris	1.3	1.75
Pristipomoides filamentosus	4.3	2.75
P. auricilla	3.6	2.25
P. flavipinnis	3.7	2.00
P. zonatus	4.65	3.00
Etelis coruscans	6.2	4.50
E. carbunculus	3.45	2.50

TABLE 9.—Annual sustainable handline yield in metric tons (t) for the age at entry which maximizes the yield per recruit for each species.

Fishing mortality (F)	Total yield (t)
0.1	35
0.5	91
[1]1.0	[1]109
1.5	114
2.0	116
2.5	116

[1]$F_{0.1}$ and $Y_{0.1}$ as defined by Gulland (1983).

The t_m can then be computed from L_m with the von Bertalanffy growth equation. The t_m for the seven species, which is assumed to be the same for both sexes of a species, is given in Table 1, and the ratio of spawning stock biomass under exploitation to the unexploited spawning stock biomass is presented for three levels of F (Table 10). As expected, the ratio decreases as F increases. However, without the spawner-recruit relationship, it is difficult to determine the extent that the spawning stock biomass can be reduced before recruitment is substantially affected. It has been suggested that as a lower bound, the spawning stock biomass should not be reduced below 20% of its unexploited level before there is a deleterious reduction in recruitment (Beddington and Cooke 1983). The level of $F = 1.0$ is the largest level of F which insures that the relative spawning stock biomass for all the species does not fall below 20% and hence the spawning stock approach also estimates the MSY for the bottom fish in the Marianas at 109 t/year.

TABLE 10.—The ratio of spawning stock biomass to unexploited spawning stock biomass for three levels of fishing mortality (F) at the age of entry which maximizes the yield per recruit.

Species	$F = 0.5$	$F = 1.0$	$F = 2.0$
Caranx lugubris	0.44	0.26	0.12
Pristipomoides filamentosus	0.46	0.33	0.25
P. auricilla	0.45	0.29	0.19
P. flavipinnis	0.45	0.26	0.12
P. zonatus	0.39	0.24	0.14
Etelis coruscans	0.31	0.20	0.13
E. carbunculus	0.58	0.42	0.30

DISCUSSION

The assessment proposed here is a multispecies approach which is most suitable for resources where prey-predator interactions are negligible. Two assumptions initially required to implement this program, i.e., constant recruitment and that the resource be essentially unexploited, can in some instances be relaxed. Simulation results suggest that if recruitment is seasonal and a pooled length frequency is constructed from individual length-frequency samples collected over the year, the length-frequency based method used here to estimate mortality produces an essentially unbiased estimate (Ralston[4]). Furthermore, the assumption that stocks be unexploited can be relaxed if an estimate of the average of F for the archipelago can be obtained. Then M can be estimated by the difference between F and total mortality, and instead of estimating unexploited recruited biomass from the CPUE survey, the biomass under F will be estimated, and yields calculated as the product of exploited biomass with the ratio of yield/biomass resulting from F computed from the Beverton and Holt yield equation.

The estimate of maximum equilibrium yield from the Beverton and Holt (1957) equation for the deep slope snappers and groupers from 22 banks in the Mariana Archipelago is 109 t annually with a fishing mortality of 1.0. About 70% of this yield would be expected to come from the southern islands of the chain, including Guam and Saipan. Another 27% would come from the northern islands and only 3% from the seamounts (Table 11).

The mean of the annual sustainable yield levels per nautical mile of 200 m contour for the northern banks, southern banks, and western seamounts are 212.9, 228.5, and 264.4 kg, respectively, with a ratio of total yield for the archipelago to the total length of the 200 m contour of 222.4 kg/nmi (95%) C.I. of 165.3-279.6) (Table 11). Detailed bathymetry data to establish a correspondence between contour length and area are available from Guguan Island in the northern Marianas, and it is estimated that 1 nmi of 200 m isobath corresponds to 0.23 nmi^2 of habitat in the 125-275 m depth range (Polovina and Roush[5]). Based on this correspondence the unit MSY of 222.4 kg/nmi of 200 m contour for the Marianas is equivalent to about 1.0 t/nmi^2 or 0.3 t/km^2.

These values suggest that the Marianas may be slightly less productive for bottom fishes than the Hawaiian Archipelago where a lower bound estimate for MSY of 272 kg/nmi of 200 m contour was obtained from a stock production model applied to commercial catch and effort data that did not include the recreational fishing component of snappers and groupers. Also, an estimate of 286 kg/nmi of 200 m contour was derived from an ecosystem model applied to an island system in the Northwestern Hawaiian Islands (Ralston and Polovina 1982; Polovina 1984).

The species composition of the catch should depend to some extent on levels of F and t_c. As F increases and t_c decreases, the contribution of

[4]Ralston, S. The effect of pooling length-frequency distributions on mortality estimation in seasonally breeding fish populations: A Monte Carlo simulation. Manuscr. in prep. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96822-2396.

[5]Polovina, J. J., and R. C. Roush. 1982. Chartlets of selected fishing banks and pinnacles in the Mariana Archipelago. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Admin. Rep. H-82-19, 7 p.

TABLE 11.—Annual sustainable yield in metric tons (t) and yield in kilograms (kg) per nautical mile (nmi) of 200 m contour for the age at entry which maximizes the yield per recruit at a level of fishery mortality of $F = 1.0$.

Banks and islands		Total yield (t/yr)		Yield (kg per nmi of 200 m contour/yr
Northern banks and islands				
Maug		2.7		262
Asuncion		2.1		188
Agrihan		5.6		304
Pagan		7.7		255
Alamagan		2.0		178
Guguan		1.7		179
Sarigan		1.6		194
Anatahan		2.5		144
38-Fathom		0.5		187
Esmeralda		2.9		237
	Total	29.3	Mean	213
Southern banks and islands				
Farallon de Medinilla		16.7		217
Saipan		13.4		254
Tinian		8.8		304
Aguijan		4.2		267
Rota		6.1		192
Guam		17.2		202
Galvez-Santa Rosa		8.6		164
	Total	76.0	Mean	229
Western seamounts				
Bank C		0.9		288
Bank D		1.1		351
Pathfinder		0.9		304
Arakane		0.6		200
Bank A		0.6		180
	Total	4.1	Mean	264

Total yield from all banks: 109 t/yr.
Total yield/length of 200 m contour = 222.3 kg/nmi.

those species to the catch with the high M/K values, particularly *P. flavipinnis* and *E. carbunculus* tends to increase (Table 12). A form of succession is, therefore, predicted as exploitation proceeds.

There are two approximations which have been used to determine MSY which express it as a fraction of the unexploited biomass. Gulland's formula estimates MSY as $0.5\ MB$, where M is the instantaneous rate of natural mortality and B is the unexploited biomass. An approach proposed by Pauly estimates MSY as $B\ 2.3w^{-0.23}$, where w is the mean of the weight (in grams) at sexual maturity and the asymptotic weight (Gulland 1983; Pauly 1983). A comparison of these two estimators with the values obtained here shows that for four out of seven species the Y/B values estimated with the Beverton and Holt equation lie between the values obtained from the Pauly and Gulland approximations.

TABLE 12.—The percentage of annual sustainable yield by species groups for two ages at entry with two levels of fishing mortality.

	Percentage of total catch by weight			
	Current age of entry		Age at entry which maximizes yield per recruit	
Species groups	$F = 0.10$	$F = 1.50$	$F = 0.10$	$F = 1.0$
Caranx lugubris	10.0	5.5	7.3	8.3
Pristipomoides filamentosus	10.3	8.5	9.4	8.2
P. auricilla	8.5	9.4	7.4	7.3
P. flavipinnis	15.6	21.7	24.3	28.7
P. zonatus	28.1	26.7	26.1	23.1
Etelis coruscans	7.6	5.1	7.1	5.0
E. carbunculus	5.9	9.2	4.6	5.9
Others	14.0	13.8	13.8	13.5

For the other three species, the Y/B values fall slightly below the Pauly and Gulland approximations for two species and substantially above for the third species. The mean Y/B values obtained by the Pauly and Gulland approximations are, moreover, in substantial agreement with the mean value of Y/B obtained with the approach proposed here (Table 13).

TABLE 13.—Annual maximum sustainable yield as a fraction of unexploited recruited biomass (Y/B_∞) at F = 1.0 together with 0.5 M and 2.3 $w^{-0.26}$.

Species groups	Y/B_∞	0.5 M	2.3 $w^{-0.26}$
Caranx lugubris	0.261	0.335	0.252
Pristipomoides filamentosus	0.262	0.270	0.296
P. auricilla	0.306	0.325	0.403
P. flavipinnis	0.680	0.475	0.348
P. zonatus	0.280	0.270	0.363
Etelis coruscans	0.201	0.175	0.226
E. carbunculus	0.375	0.515	0.289
Mean	0.338	0.338	0.311

ACKNOWLEDGMENT

This paper is the result of the Resource Assessment Investigation of the Mariana Archipelago at the Southwest Fisheries Center Honolulu Laboratory, NOAA.

LITERATURE CITED

ANONYMOUS.
1977. Inventaire critique des données utilisées pour l'étude de la reproduction. *In* Rapport du groupe de travail sur la reproduction des espèces exploitées du Golfe de Guinée, p. 8-20. ORSTOM-ISRA, Dakar.

BANNEROT, S. P., AND C. B. AUSTIN.
1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Trans. Am. Fish. Soc. 112:608-617.

BEDDINGTON, J. R., AND J. G. COOKE.
1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242, 47 p.

BEVERTON, R. J. H., AND S. J. HOLT.
1956. A [illegible] rates in exploited [illegible] sources of bias in catch sampling. Rapp. P.-v. Réun. Cons. int. Explor. Mer 140:67-83.
1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. II, vol. 19, Mar. Fish., G. B. Minist. Agric. Fish. Food, 533 p.
1966. Manual of methods for fish stock assessment. Part II. Tables of yield functions. FAO Fish. Tech. Pap. 38 (Rev. 1), 67 p.

BROUARD, F., AND R. GRANDPERRIN.
1984. Les poissons profonds de la pente recificale externe à Vanuatu. Mission ORSTOM, Vanuatu, Notes et Documents D'Océanographie 11. 131 p.

CSIRKE, J., AND J. F. CADDY.
1983. Production modeling using mortality estimates. Can. J. Fish. Aquat. Sci. 40:43-51.

GULLAND, J. A.
1969. Manual of methods for fish stock assessment. Part 1. Fish population analysis. FAO Fish. Ser. 3, 154 p.
1983. Fish stock assessment. A manual of basic methods. John Wiley & Sons, 223 p.
1984. Advice on target fishery rates. ICLARM Fishbyte 2(1):8-11.

MUNRO, J. L.
1983. A cost-effective data acquisition system for assessment and management of typical multispecies, multi-gear fisheries. ICLARM Fishbyte 1(1):7-12.

PAULY, D.
1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. (234), 52 p.

PAULY, D., AND G. I. MURPHY (editors).
1982. Theory and management of tropical fisheries. ICLARM Conf. Proc 9, 360 p. ICLARM, Manila, Philippines, and Division of Fisheries Research, CSIRO, Cronulla, Australia.

POLOVINA, J. J.
1984. Model of a coral reef ecosystem. I. The ECOPATH model and its application to French Frigate Shoals. Coral Reefs 3:1-11.
1986a. A variable catchability version of the Leslie model with application to an intensive fishing experiment on a multispecies stock. Fish. Bull., U.S. 84:423-428.
1986b. Variation in catch rates and species composition in handline catches of deepwater snappers and groupers in the Mariana archipelago. Proc. 5th Int. Coral Reef Congr. 1985, Tahiti.

RALSTON, S.
1986. An intensive fishing experiment for the caridean shrimp, *Heterocarpus laevigatus*, at Alamagan Island in the Mariana Archipelago Fish. Bull., U.S. 84:927-934.
In press. Length-weight regressions and condition indices of lutjanids and other deep slope fishes from the Mariana Archipelago. Micronesica.

RALSTON, S., AND J. J. POLOVINA.
1982. A multispecies analysis of the commercial deep-sea handline fishery in Hawaii. Fish. Bull., U.S. 80:435-448.

RICKER, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

SAILA, S. B., AND P. M. ROEDEL (editors).
1979. Stock assessment for tropical small-scale fisheries. Proceedings of an International Workshop Held September 19-21, 1979, at the University of Rhode Island, Kingston, RI, 198 p.

WETHERALL, J. A., J. J. POLOVINA, AND S. RALSTON.
In press. Estimating growth and mortality in steady state fish stocks from length-frequency data. *In* D. Pauly and G. R. Morgan (editors), Length-based methods in fishery research. The ICLARM/KISR Conference on the Theory and Application of Length-Based Methods for Stock Assessments, Sicily, Italy, February 1985. Vol. 1.