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CHAPTER 4

Deepwater Demersal Fish

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I. INTRODUCTION

Demersal fisheries are a very important component of total world catches. The FAO 1987 Yearbook of Fishery Statistics (FAO, 1989) reports total landings of marine finfish equaling 68 million metric tonnes (t). The three major species groups of demersal finfish - flounders, cods, and redfishes - account for 20 million t or just under one third of the total. By comparison, tuna and billfish landings were reported at 3.4 million t for the same year.

The majority of the demersal finfish yields are from the fisheries on wide continental shelves and slopes (*e.g.* the Bering Sea and Patagonia) at depths of 50 to 500 m. Unfortunately, shallow reef areas around the Pacific islands tend to drop quite rapidly to abyssal depths, leaving relatively little habitat area for deep-slope species.

Snappers (family Lutjanidae) and groupers (family Serranidae) (included in the redfishes group mentioned above) are important components of the demersal fisheries catch throughout the tropical and temperate oceans. In general, the shallower (<100 m) dwelling members of these families are of relatively small size and, though commercially important, comprise only a minor portion of the catch at these depths (Munro, 1987).

Finfish catches on the deep (100-500 m) slopes of the Pacific islands, however, are dominated by a few species of snappers and groupers which tend to be of larger size than shallower species (Munro, 1987). These deep-slope species have not been a major component of the traditional, subsistence fisheries in the Pacific areas, but because of their demand as a high-quality product for tourist and export markets, they have become an important component of developing commercial fisheries.

II. LIFE HISTORY AND POPULATION BIOLOGY

TAXONOMY

The taxonomy of the deep slope species is relatively stable; recent reviews and keys to species are in Anderson (1987) and Randall (1987). The major area of taxonomic contention is found in the snapper genus *Etelis*, where *E. carbunculus* (Cuvier 1828) is in current usage for both the small sized North Pacific individuals, such as the 26-63 cm fork length (FL) fish found in Hawaiian waters (Everson, 1986), and the much larger South Pacific individuals, such as those reaching 112 cm FL in Vanuatu (Brouard and Grandperrin, 1984). The question remains unanswered as to whether one or two species are involved. Support for the two-species hypothesis includes the uniquely bimodal length-frequency distributions reported by Lokani *et al.* (1990) and King *et al.* (*in prep.*) for fish from Papua New Guinea and Western Samoa, respectively.

DISTRIBUTION

Most of the deep slope demersal fish species are widely distributed throughout the central, western and South Pacific although species richness tends to decline with distance from the Indo-Pacific faunal centre, leaving areas like Hawaii with somewhat fewer species. Table I lists many of the more commonly caught species from several families.

Snappers of the subfamilies Etelinae and Apsilinae and groupers of the subfamily Epinephelinae are the most important elements of this fishery both in terms of landings (ranging from 70 per cent to over 90 per cent of the total catch) and value (because of high quality and marketability). Biological discussions and yield estimates presented in this chapter will be restricted to members of these two families.

Although the majority of the more important species are wide ranging, their relative contribution to the catch varies considerably with location. In Hawaii, *Pristipomoides filamentosus* (Valenciennes 1830) is the most abundant species, comprising about 20-40 per cent of the demersal catch (Moffitt, 1980; Polovina and Moffitt, 1980; Ralston and Kawamoto, 1987; 1988). In the Marianas, on the other hand, *P. zonatus* (Valenciennes 1830) is the most abundant species, where it contributes over 50 per cent of the total deepwater demersal catch (Polovina, 1985; Ralston and Williams, 1988). In many other areas, *Etelis* spp. dominate the deepwater finfish catch (King *et al.*, *in prep.*; Grandperrin and Kulbicki, 1988; Lewis *et al.*, 1988; Nath and Sesewa, 1990).

HABITAT

Adults and large juveniles of the deepwater snappers and groupers tend to be caught over high relief features (e.g. pinnacles or steep slopes) at depths of 100-500 m, indicating a preference for this type of habitat. Submersible observations of both natural (Ralston *et al.*, 1986) and artificial habitats (Moffitt *et al.*, 1989) suggest that snappers (specifically those of the genus *Pristipomoides*)

Table I. List of common deepwater demersal fish species.

Family Lutjanidae
Aphareus rutilans (Cuvier 1830)
Aprion virescens (Valenciennes 1830)
Etelis carbunculus (Cuvier 1828)
E. coruscans (Valenciennes 1862)
E. radiosus (Anderson 1981)
Paracaesio caerulea (Katayama 1934)
P. kusakarii (Abe 1960)
P. stonei (Raj and Seeto 1983)
P. xanthura (Bleeker 1869)
Pristipomoides auricilla (Jordan, Evermann, and Tanaka 1927)
P. filamentosus (Valenciennes 1830)
P. flavipinnis (Shinohara 1963)
P. multidens (Day 1870)
P. sieboldi (Bleeker 1857)
P. zonatus (Valenciennes 1830)
Family Serranidae
Cephalopholis aurantia (Valenciennes 1828)
C. igarashiensis (Katayama 1957)
C. sexmaculata (Ruppell 1830)
C. sonnerati (Valenciennes 1828)
Epinephelus chlorostigma (Valenciennes 1828)
E. lanceolatus (Bloch 1790)
E. morrhua (Valenciennes 1833)
E. septemfasciatus (Thunberg 1793)
Saloptia powelli (Smith 1963)
Variola louti (Forsskal 1775)
Family Lethrinidae
Gymnocranius euanus (Gunther 1879)
G. griseus (Schlegel 1844)
Lethrinus rubrioperculatus (Sato 1978)
Family Carangidae
Caranx lugubris (Poey 1861)
Elegatis bipinnulatus (Quoy and Gaimard 1824)
Seriola dumerili (Risso 1810)
S. rivoliana (Valenciennes 1833)
Family Scombridae
Gymnosarda unicolor (Ruppell 1836)

form loose aggregations of up to at least 50 individuals around such high relief features.

Brouard and Grandperrin (1984) and Ralston and Williams (1988) list depth ranges for many of the deepwater demersal species. In short, carangids, lethrinids, and many epinephelids are shallower dwellers (<120 m), *Pristipomoides* spp. and some epinephelids are found at intermediate depths (120-240 m) and *Etelis* spp. and a few epinephelids are deeper dwellers (>240 m).

Sundberg and Richards (1984) report that individual fish size increases with depth when all species are pooled. Ralston and Williams (1988) found, however, that, within species, size is poorly correlated with depth, indicating that increases in mean fish size with depth are due to changes in species composition, not depth stratification by size for individuals of any particular species.

Some species may not be restricted to deep slope, high relief habitat. Evidence suggests that individuals of *P. filamentosus* in Hawaii, for example, undergo a diurnal migration from deeper daytime high relief areas at depths of 100 to 200 m, to shallower night flat shelf areas at depths of as little as 30 to 80 m (Moffitt, 1980). This behavior has not been demonstrated for other species or areas. In contrast to the snappers, deep slope groupers are probably solitary and territorial in nature, as are their shallower dwelling congeners (Parrish, 1987; Shapiro, 1987).

Although adult habitat for most of the deep slope snappers and groupers is well known, the nursery grounds for newly settled and young juveniles have not been identified. Recent studies in Hawaii suggest that juveniles may utilize the flat, featureless areas of banks, avoiding the high relief areas where larger fish (potential predators) accumulate (Parrish, 1989; Moffitt and Parrish *unpubl. data*).

Large concentrations of juvenile opakapaka, *P. filamentosus*, have been found on the featureless, silty bottom at 70-100 m depths off of Kaneohe Bay, Oahu. At this site, they dominate the rod and reel catch (well over 90 per cent of the catch). They apparently utilize this area for a period of about 6-9 months (FL 7-20 cm), then move deeper to higher relief areas.

During their stay within this habitat, juvenile opakapaka appear to undertake a diurnal migration similar to that described above for the adults. A single sonic tag track showed a 19 cm FL individual migrated cross-shelf from a daytime location at 85 m depth to a night time location at 75 m depth. These movements occurred consistently at dawn and dusk over the 5 day life of the tag (Moffitt and Parrish, *unpubl. data*).

Similarly, six newly settled specimens (ca. 25 mm standard length (SL)) of Hawaii's deep slope grouper, *Epinephelus quernus* (Seale 1901), have been collected from lobster traps set at 40-80 m on flat sand and mud areas off Kaneohe Bay, Oahu and off Maro Reef in the Northwestern Hawaiian

Islands. When captured, these specimens had pelagic coloration (translucent pink with darker vertical bars) and a black "flag" on the longest dorsal spine when captured. Two specimens transformed to juvenile coloration (black with white dots) and lost the "flag" on the dorsal spine within 4 days of shipboard captivity.

FEEDING

Studies on the feeding habits of deepwater snappers and groupers have been hampered by the great depths involved. The fish tend to regurgitate stomach contents during hauling and frequently are badly embolized with their stomachs completely everted (Seki and Callahan, 1988). Fortunately, some material often remains in the mouth or in the gill rakers, allowing at least a qualitative analysis of prey items. Feeding of both snappers and groupers undoubtedly occurs at the deep-slope, high relief features where they are hooked, but distance of feeding off the bottom is difficult to determine.

Fishermen report that groupers are generally hooked on the bottom, whereas snappers can be caught either on the bottom or, in many cases, several meters above the bottom. Dietary studies support the differences between these families, with benthic fish and crustaceans being important prey items for species of both families and pelagic urochordates (e.g. *Salpida* spp., *Pyrosomida* spp.) being important prey items for many species of *Pristipomoides* (Kami, 1973; Oda and Parrish, 1981; Seki, 1984; Parrish, 1987; Seki and Callahan, 1988).

REPRODUCTION

Reproductive strategies differ greatly between the two major families included in this chapter. Studies have indicated that deepwater snappers are serial spawners able to spawn several times over a prolonged breeding season (Min *et al.*, 1977; Ralston, 1981; Everson, 1984; Kikkawa, 1984; Grimes, 1987). Although the number of spawning episodes per season has not been established for any species, ovaries typically contain three size classes of oocytes (Grimes, 1987). Ova size-frequency modes, however, are likely unrepresentative of spawning frequency in serial spawners (Hunter and Goldberg, 1980; DeMartini and Fountain, 1981).

Large female *E. carbunculus* in Hawaii develop ripe ova earlier in the breeding season and remain in breeding condition longer than those of smaller individuals (Everson, 1984), suggesting that larger females spawn more batches than smaller ones. Analysis of gonosomatic indices, coupled with visual staging of ova, suggests that deepwater snappers spawn in the summer (May to September in the North Pacific (Everson, 1984; Kikkawa, 1984; Ralston and

Williams, 1989; Everson *et al.*, 1989) and November to May in the South Pacific (Brouard and Grandperrin, 1984)).

Sexual maturity is attained at approximately 50 per cent of maximum length for deepwater species (Grimes, 1987). Fecundity for those species examined increases with fish size and reportedly ranges from 300,000 to 2,000,000 eggs, depending on size and species (Min *et al.*, 1977, Everson 1984, Kikkawa 1984). However, realistic estimation of annual egg production is very difficult, because deepwater snappers are serial spawners with an unknown number of spawning episodes per season.

Reproduction of groupers differs markedly from that of snappers. Although data on the reproductive biology of Pacific deepwater species are lacking, all grouper species studied to date have been shown to be protogynous hermaphrodites (Shapiro, 1987).

The general pattern of grouper reproduction presented by Shapiro (1987) is as follows. The breeding season is abbreviated (peaking for 1-2 months) with an unknown number of spawnings per individual male or female. Spawning often takes place in large spawning aggregations, during which time stocks become unusually susceptible to fishing pressure. Fecundity for the deep sea species has not yet been determined, but ranges from 100,000 to 5,000,000 in other grouper species (Shapiro, 1987). The stimulus for sex change from female to male is unknown and could be related to size, age, or social interactions.

LARVAL BIOLOGY AND ECOLOGY

Relatively little is known of the taxonomic relations or ecology of deep-slope snapper and grouper larvae. Both snappers and groupers have pelagic eggs and larvae. But, snapper and grouper larvae are a minor component of larval fish catches, contributing to the lack of ecological information on these species. Larvae of both families avoid surface waters during the day but become more evenly distributed vertically at night. Larvae of eteline snappers are generally found in oceanic waters, in contrast to larvae of other snappers that are most abundant over shelf waters. Grouper larvae are also most abundant over shelf waters, but as identification to species is not currently possible, the horizontal distribution of larvae of deepwater species is not known (Leis, 1987). Studies are in progress to identify the larvae of several species of *Etelis, Aprion,* and *Pristipomoides* (Leis, 1987). Leis (1987) reports fertilized eggs of *P. seiboldii* (Bleeker 1857) are 0.88-0.98 mm in diameter and hatch in about 36 hours at temperatures of 23-25° C.

GROWTH

The most commonly used model for expressing growth in fisheries studies is the von Bertalanffy growth formula, which for growth in length takes the form:

$$L_t = L_\infty(1-e^{-K(t-t_0)})$$

where L_t is the predicted length at age t, L_∞ is the asymptotic length, K is the growth constant, and t_0 is the hypothetical "age" where the fish is at zero size. Estimates of growth parameters may be obtained through one of three basic sources, tag and recapture techniques, analysis of length-frequency distributions, or interpreting temporal markings on hard parts such as scales, vertebrae, and otoliths (Manooch, 1987). Various methods are found for utilizing each data source and each method has its own strengths and weaknesses.

Tag and recapture techniques give the most direct information on growth. Fish are measured when first caught, tagged with noticeable marker and released. When recaught the fish are measured again and the increase in length between marking and recapture is equated to growth. Jones (1979) reviews tagging materials and methods. In practice, growth rates obtained in tag and recapture studies are minimum growth rates, as fish are often stressed by capture, handling, and tagging operations resulting in a period of less than optimum growth. Tag and recapture studies have not been conducted on Pacific deepwater demersal species, and would be particularly problematic because these fish are usually near death from damage caused by their expanding gas bladder when brought to the surface.

The various methods of analysing length-frequency distributions rely on distinguishing length modes from large representative samples that are correlated to age classes (Pauly and Morgan, 1987). The Petersen method (Petersen, 1892) assigns ages to the multiple length-frequency peaks in a single large sample, whereas the Modal Class Progression Analysis method (George and Banerji, 1964) links length-frequency peaks from several samples taken at known time intervals. There are several computer programs available that assist in modal identification and parameter estimation (Mathews, 1974; Skillman and Yong, 1976; McNew and Summerfelt, 1978; Schnute and Fournier, 1980), including the now popular Electronic Length-Frequency Analysis (ELEFAN) method developed by Pauly and David (1981).

The benefits of using length-frequency analysis for growth estimation include the ease of data collection (often obtainable from existing catch data) and the lack of required technical skills for processing. On the negative side, several conditions must be met for meaningful results to be obtained. The sample must be representative of the size distribution of the stock and not biased by gear selectivity or varying size distribution by depth of capture. Best results are obtained from species with short breeding seasons and fast growth. In long-lived species, the older age class modes often overlap as they near asymptotic length. This overlap leads to an underestimate of the number of year classes involved such that, while L_∞ estimates may be accurate, K is overestimated.

Unfortunately, deepwater snappers and groupers are long lived, slow growing and, at least in snappers, have prolonged breeding seasons, making them poor candidates for length-frequency analysis. Few studies have applied these methods to Pacific deepwater demersal species (Manooch, 1987). Pauly and Ingles (1981) obtained estimates of growth parameters using ELEFAN for *Epinephelus sexfasciatus* (Valenciennes 1828) from the Philippines (L_∞=309 mm standard length (SL), K=0.510) and *Plectropomus leopardus* (Lacepede 1802) from Australia (L_∞=647 mm total length (TL), K=0.250), but Langi (1990) determined that ELEFAN procedures were inappropriate for three species of snappers, *P. flavipinnis* (Shinohara 1963), *P. filamentosus,* and *E. coruscans* (Valenciennes 1862), from Tonga.

Otoliths (sagittae) have been the most commonly used hard part in fish growth determinations and the only one used to date for tropical deepwater snappers and groupers. In temperate regions, where fish growth rates vary seasonally, annual marks are formed on otoliths. These increments are often easy to observe after minimal otolith preparation and low-powered magnification. Annular increments are also reported for some tropical species (Loubens, 1978; Morales-Nin and Ralston, 1990) including some individuals of *P. zonatus* and *P. filamentosus* (Uchiyama and Tagami, 1984; Ralston and Williams, 1988) but, unfortunately, are not easily distinguishable even when present.

Pannella (1971; 1974) reported that daily growth increments could be discerned on fish otoliths, even in tropical species. Since that time otoliths of several deepwater tropical species have been examined using light microscopy and "daily" increments enumerated for age and growth determination (Ralston and Miyamoto, 1983; Brouard and Grandperrin, 1984; Uchiyama and Tagami, 1984; Radtke, 1987; Ralston and Williams, 1988).

Although very precise age estimates can be obtained under optimum conditions, several problems do arise when enumerating otolith daily growth increments. The shape and size of deepwater snapper and grouper otoliths do not lend them to whole mounting for microscopic increment enumeration. Instead, otoliths are generally embedded in plastic resin and thin sectioned (<1 mm) with a low-speed saw such that the center of the otolith (referred to as the "nucleus" or "focus") and the postrostral tip are included in the section.

Comprehensive increment counts are difficult to obtain in sections of deepwater snapper and grouper otoliths, because large areas are often cloudy, the degree of cloudiness varying with the individual preparation and species involved. Based on the assumption that cloudy areas are caused by deficiencies in preparation, the increment width method (Ralston and Miyamoto, 1983; Ralston, 1985; Ralston and Williams, 1989) was developed. In this method, increment widths are measured in several small sections along the axis of the otolith preparation and the total number of increments estimated through integration. Only areas where increments are clearly defined are utilized. Using

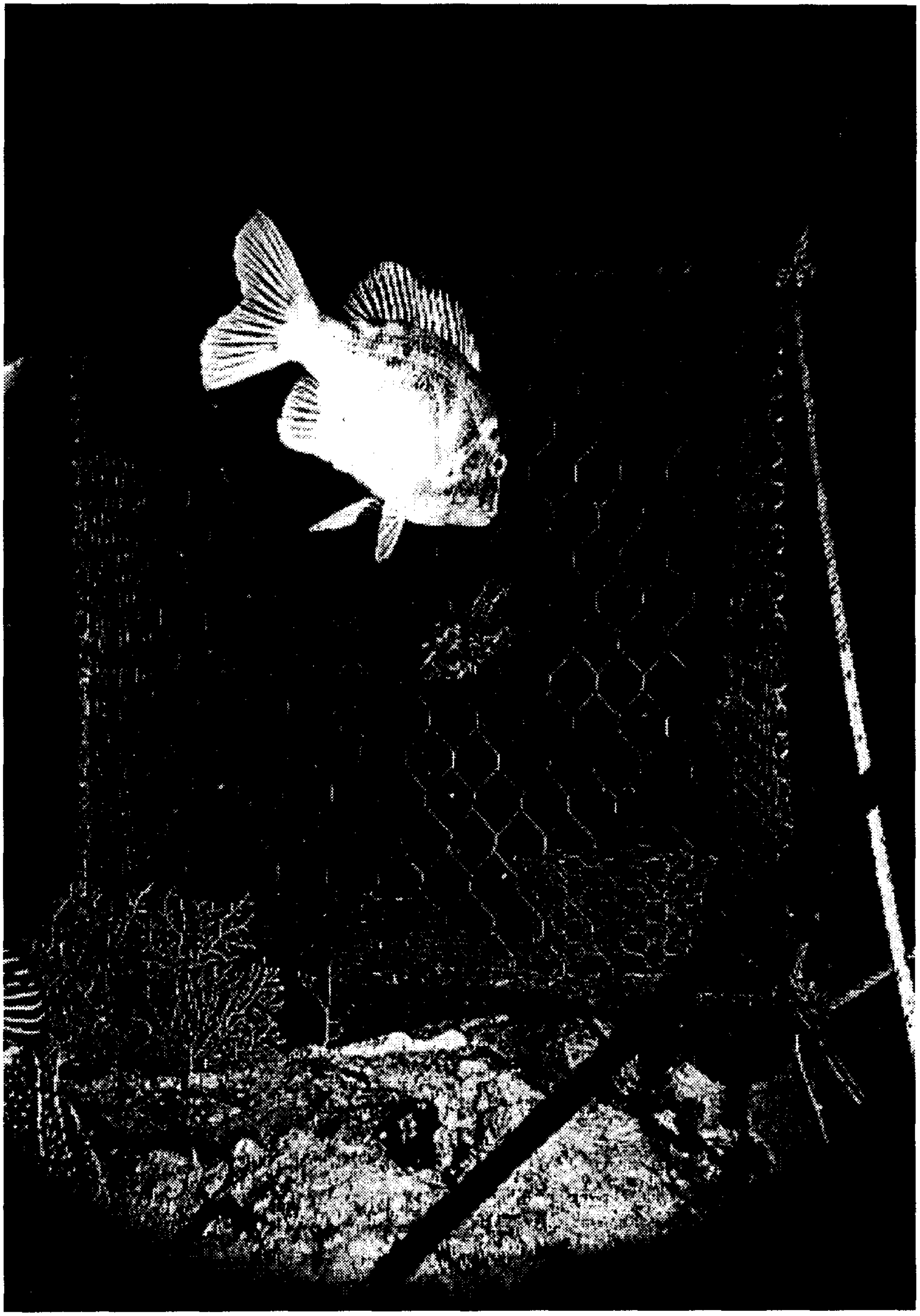

Figure 1. ***Pristipomoides multidens*** **attracted to a trap set for *Nautilus* spp. at 270 m. (Photograph kindly provided by Bruce Saunders.)**

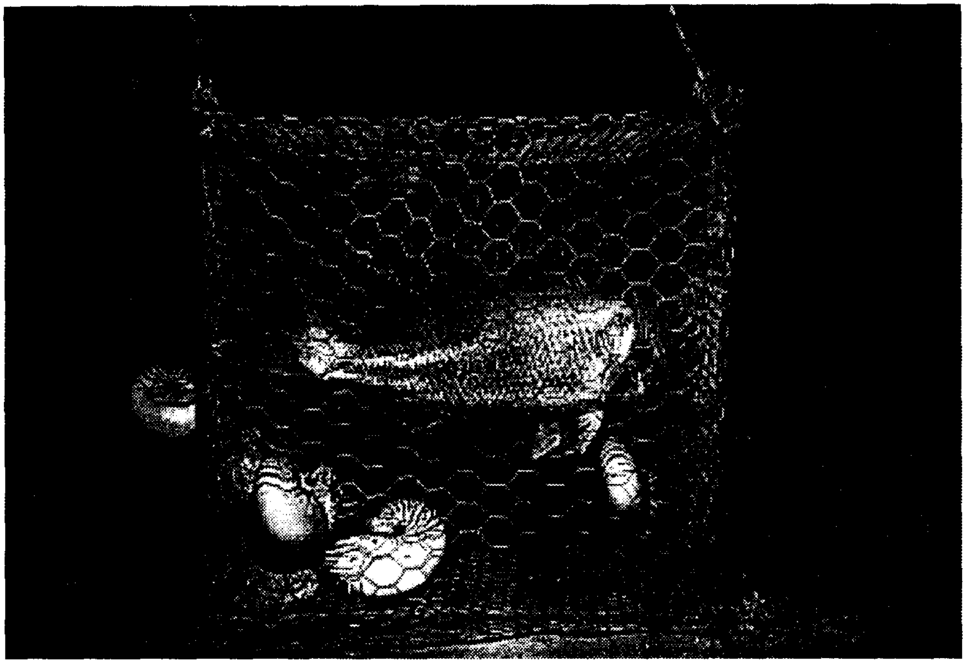

Figure 2. *Gnathodentex mossambicus* circling a baited trap at 167 m. (Photograph kindly provided by Bruce Saunders.)

scanning electron microscopy (SEM), however, Morales-Nin (1988) and Morales-Nin and Ralston (1990) have shown that the cloudy areas on the otoliths of some tropical species, including the shallow water snapper, *Lutjanus kasmira* (Forsskal 1775), are actually areas of slow growth with increments too narrow to be distinguished with light microscopy. They suggest that otoliths of prospective species be first examined using SEM, then, if all increments are wide enough to resolve under light microscopy, future otoliths could be analysed by either whole counts or the increment width method for age estimation of that species (Morales-Nin and Ralston, 1990).

Even when precise counts are obtained, verification of the temporal nature of the increments and their continued deposition for all ages of fish must be obtained. Evidence suggests increments are indeed daily in nature, but that by maturation (at about 3 years for *Pristipomoides* spp.) breaks appear in the daily deposition of increments making counts inaccurate (fewer increments counted leading to higher estimates of K) (Ralston and Miyamoto, 1983; Uchiyama and Tagami, 1984). This being true, estimates of K may be biased either by including mature fish in the sample, which will have fewer increments than days of age, leading to an overestimate of K, or by restricting the sample to juvenile fish and extrapolating growth rates for larger fish.

Familial characteristics have been observed in the relationships of various growth parameters (Beverton and Holt, 1959; Cushing, 1968; Pauly, 1980). Using the growth performance index ($\varnothing'$) method of Pauly and Munro (1983), Manooch (1987) summarized the available snapper and grouper growth information. He found that snapper and grouper data overlapped greatly and could not be separated statistically. The resulting formula for pooled species of both families was: $\log_{10}(K) = 1.098 - 0.658 \log_{10}(L_\infty)$ with standard error estimates of 0.066 and 0.183 for the slope and intercept, respectively. Manooch (1987) reported mean values for maximum age of 10.49 years for lutjanids and 17.00 years for serranids with corresponding mean K values of 0.203 and 0.218 per year, respectively. Calculation of $\varnothing'$ could be used to determine growth estimates if data from future studies fall within a reasonable range.

MORTALITY

The instantaneous total mortality rate from all causes (Z) measures loss of individuals from the population. It is subdivided into two additive components, fishing mortality (F) and natural mortality (M), such that $Z = F + M$. In general total mortality is measured in one of three ways: 1) though tag-and-recovery methods (Ricker, 1975), 2) by measuring survivability of an age specific cohort over time (Gulland, 1955), and 3) by designating cohort sizes from a single sample using existing age-length information (Gulland, 1955).

As previously mentioned, capture, handling and tagging procedures stress fish and can cause an unknown increase in mortality. This is particularly true in the deepwater snappers and groupers where expanding gas bladders result in everted stomachs and potential internal damage. Grimes *et al.* (1983) developed a technique using detachable hooks to tag deepwater fish without bringing them to the surface. Although this method works well for monitoring fish movement, where small numbers of tag recovery can be sufficient, it does not work well for mortality (or growth) estimation. Problems stem from lack of knowledge as to species and size of tagged fish and unknown levels of additional mortality, both real (due to infection or impaired feeding) and apparent (due to sloughing of tags). In tank studies, Shiota (*unpubl. data*) tagged the shallow water snapper, *Lutjanus kasmira*, with varying types of detachable hook tags and observed over 50 per cent tag loss within 10 days regardless of tag type.

An important variation of the third method involves analysis of a single length-frequency distribution to estimate the ratio of Z/K (Wetherall *et al.*, 1987). An independent estimate of K allows separation of the ratio to obtain an estimate of Z. Separation of Z into its two components can be very difficult requiring a good time series of Z and fishing effort information. When length-frequency samples are obtained from unfished populations, however, natural mortality estimates are obtained since Z then equals M.

The Wetherall method has been used for estimating M (and L_∞) for many deepwater snapper and grouper species (Brouard and Grandperrin, 1984; Ralston, 1987; Ralston and Williams, 1988). Care must be taken, to ensure the population under study is in equilibrium. Somerton and Kobayashi (1991, *in prep.*) ran a simulation model showing considerable bias in Z/K and L_∞ values with disruption of equilibrium due to changes in F or recruitment (R). They suggest that equilibrium conditions should be verified by comparing length-frequency distributions from several consecutive years with a Chi-square test before relying on estimates derived from the Wetherall method.

Natural mortality can also be predicted empirically due to its relationship to von Bertalanffy growth parameters K and L_∞ and the mean environmental temperature (T) (Pauly, 1980):

$$\log M = 0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T.$$

Ralston (1987) suggests that in this relationship the value of K is of prime importance and that the addition of terms relating to L_∞ and T provide little independent information. Therefore, good estimates of K are all that are needed for a good prediction of M. For snappers and groupers, Ralston found this relationship to be $M = 0.0189 + 2.06K$.

III. RESOURCE ASSESSMENT

Most of the recent studies on deepwater demersal fish have focused on resource assessment. In fisheries where a long time series of catch and effort data is available, estimates of maximum sustainable yield (MSY) can be obtained using surplus production models. The Schaefer model has been applied to the multispecies deep-slope demersal fishery in Hawaii, resulting in an estimated MSY of about 0.27 $t.nmi^{-1}$ of 200 m isobath (Ralston and Polovina, 1982).

Unfortunately, a sufficiently long time series of data is not available for other Pacific Island areas because of the undeveloped or recently developed nature of the fishery in these areas. Thus, surplus production models cannot be applied, and alternate assessment methods must be sought.

Three such methods have been applied recently to tropical Pacific deepwater snappers and groupers. These methods are 1) the Gulland method (Gulland, 1969) which estimates MSY as a fraction of the product of M and unexploited exploitable biomass (B_0), 2) the Pauly method (Pauly, 1983) which estimates MSY as a function of fish weight, and 3) the Beddington and Cooke (1983) modification of the Beverton-Holt equation estimating MSY as a function of B_0, the ratio of M to K and the age at recruitment to the fishery (t_r). In all three approaches, estimates of MSY rely on first estimating B_0 and other biological parameters (see Polovina and Ralston, 1986).

BIOMASS

Depletion studies have been used to obtain estimates of B_0 of deepwater snappers and groupers. Typically a small, isolated, virgin fishing area is intensively fished until a noticeable reduction in catch rates has been achieved (Polovina, 1986). If the period of depletion is short (< 9 mo), the catch per unit effort (CPUE) data are regressed on the cumulative removed biomass to obtain estimates of catchability (q) and B_0 following the Leslie model (Ricker, 1975). When the period of fishing is greater than 9 mo, these same estimates are obtained by applying the Allen depletion method (Sainsbury, 1984) which requires an estimate of M to estimate q, B_0 and mean recruitment (R).

Estimates of q and B_0 obtained by these methods are specific to the study area involved and are best standardized to a measure of area to allow comparison with other studies. The most frequently utilized standardized area unit is the length of 200 m isobath (Ralston and Polovina, 1982). Results obtained for several Pacific islands countries are summarized in Polovina *et al.*, (1990). Interestingly, estimates of B_0 for seamounts have been considerably greater than those for island fishing grounds: a median value of 2.7 $t.nmi^{-1}$ of 200 m isobath (range 1.4 to 8.5) versus 0.7 (range 0.2 to 2.3), respectively. Ralston (1988) also noted that the deepwater demersal fish off seamounts in the Marianas were heavier and more robust than those from other locations.

YIELDS

Estimates of MSY for many of the Pacific islands countries by using the Gulland, Pauly, and Beddington-Cooke methods are summarized in Polovina *et al.* (1990). The estimates are expressed as the ratio of MSY to B_0 and range from 0.06 to 0.34, depending on the method used, the country of data origin, and the estimate of M applied. Based on the median values estimated for B_0 for seamount and island fishing areas considered individually, MSY values range from 0.16 to 0.92 $t.nmi^{-1}.yr^{-1}$ for seamounts and from 0.04 to 0.27 $t.nmi^{-1}.yr^{-1}$ for island areas.

Total MSY for individual countries are calculated as the product of MSY per nautical mile of 200 m contour and the estimated length of 200 m contour for that country. Landings for Tonga and Fiji in 1988 exceeded estimated MSY levels (Polovina *et al.*, 1990). This does not mean, however, that the current level of fishing is in excess of the level of fishing that would produce MSY.

It is suggested that MSY is achieved at levels of fishing where $F = M$ (Francis, 1974; Beddington and Cooke, 1983; Polovina, 1987). Estimates of F for both Tonga and Fiji (Polovina *et al.*, 1990) fall within the range of M estimates for snappers and groupers (Ralston, 1987), which suggests that stocks probably are not yet overfished and landings in excess of MSY are likely due to a "fishing down" process and will continue to decline at current fishing levels until an equilibrium yield is obtained.

IV. FISHERIES DESCRIPTION

In general, traditional demersal fishing in the Pacific Islands has been concentrated on the shallow (<30 m) reef areas, with fishing in deeper waters targeting tunas, mackerels and other pelagic fishes (Dalzell, 1990). The deepwater demersal fisheries of most Pacific islands countries are either in the pre-development, survey stage or in early stages of commercial development. Hawaii is a notable exception with a 50 year history of commercial bottom fishing.

The market for deep slope demersal fish is a fresh fish market, so fish are iced and fishing trips are limited to about 10 days. Fishing fleets differ from country to country in the size of vessels and the level of technology utilized to locate fishing grounds and retrieve gear, but basic fishing techniques are very similar, regardless of location or fishery developmental stage.

In general, lines are hand-held and fished with the vessel either at anchor or drifting over depths of 100-500 m. Multiple hooks are generally used with baits varying, with availability, from stripped squid to tuna bellies and other fish parts. Bottom longline gear has been used in a few areas as a research and commercial gear (Lewis *et al.*, 1988; Shiota, 1987), but does not appear practical for commercial purposes.

In Hawaii the fully commercial vessels are generally 10-15 m in length with inboard diesel engines; many fishing grounds are located over 200 nmi from port, with trips lasting about 10 days. These vessels are equipped with depth sounders (mostly colour) and electronic navigational aids (e.g. Loran or satellite navigation systems) to assist in the location of suitable fishing grounds and hydraulic reels to haul fishing gear.

In addition to these large commercial vessels, Hawaii supports a small (<10 m in length) craft fleet which includes recreational and part-time fishermen in addition to a few full-time commercial fishermen. Operators of these small vessels generally fish close to port on 1-3 day trips. As with the larger vessels, most have depth sounders which are used in conjunction with land bearings to locate fishing grounds. Fishermen on these vessels typically use electric or hydraulic reels to haul lines, although a few fishermen still haul lines by the traditional hand-over-hand method.

In most other Pacific islands countries, vessels in the deep-slope demersal fishery are fewer than 10 m in length and either diesel or outboard motor powered. High technology equipment (*i.e.* depth sounders, electronic navigational systems and hydraulic or electric reels) is not common. Instead, fishing grounds are located using land bearings, and the FAO developed Samoan hand reel is in general use for gear retrieval (see Dalzell (1990) for a diagram of this reel). Trips are generally close to port and last 1-3 days.

V. MANAGEMENT CONCERNS

Preliminary estimates of MSY and its associated level of fishing effort are important to managers. In countries with a developing fishery, governments often contribute financially to the building of a fishing fleet, as well as to shoreside support facilities such as ice houses. Foreknowledge of anticipated sustainable landings can help determine whether these expenditures are warranted. In a developed fishery, these same estimates are useful in determining when overfishing occurs. Ideally, after a fishery is developed, a time series of catch and effort data will have accumulated that would allow application of a surplus production model to the fishery, thereby refining estimates of MSY and its associated fishing effort.

Overfishing is divided into two categories. Growth overfishing occurs when fish are harvested at suboptimal size, thereby reducing overall landings. When this happens in a trawl fishery, rectification often takes the form of regulations increasing mesh size. In the deepwater demersal fisheries, however, increasing hook size does not strongly affect the size distribution of the catch (Ralston, 1982; 1990). Another corrective measure might involve establishing a minimum size limit for the catch. This is applicable to these particular fisheries only to the degree that specific sizes of fish can be targeted in the fishing operation. Unfortunately, snappers and groupers caught at the depths involved in these fisheries are landed in a moribund state due to expanded gas bladders and release of sublegal sized fish would not result in a high level of survival.

The second type of overfishing is recruitment overfishing. This occurs when the spawning stock biomass (B_{ss}) is reduced to such a low level that recruitment suffers. Unfortunately, spawner-recruit relationships are not known for any of the snappers and groupers. In the absence of this type of information, Beddington and Cooke (1983) suggest that B_{ss} should not be reduced to lower than 20 per cent of its unexploited level. Fortunately, with knowledge of the length at maturity (L_m), B_0 and the unexploited length-frequency distribution, this biomass ratio may be monitored. Of course, direct estimates of species-specific spawner-recruit relationships are preferable and work should continue along this line.

An additional management problem arises in a multispecies fishery when some of the pertinent species are overfished and others are not. Ralston and Kawamoto (1987) report that three of the five most important species of the deep-slope fishery in the main Hawaiian Islands are overfished; of the remaining two species, one is at a near optimum level of yield and the other is underutilized. Establishing species-specific quotas may be the best management action in this case; however, effectiveness of this action would depend on the ability of fishermen to target particular species within the fishery.

Habitat enhancement is another area of concern for fishery managers. Are the deepwater snappers and groupers habitat-limited? Are there areas within their appropriate depth ranges that could be enhanced with artificial reefs? Care must be utilized before such "enhancement" is attempted. As suggested for juvenile *P. filamentosus* (Parrish, 1989; Moffitt and Parrish, *unpubl. data*), nursery habitats may be the same featureless, "unproductive" areas where habitat enhancement projects appear most promising. If buried by reef-making materials, juvenile habitat may be reduced. Also, because adults are known to aggregate around high relief structures, artificial reefs may increase catchability to such a degree that any increases in production are offset by overfishing (Moffitt *et al.*, 1989).

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