Bottomfish Stock Assessment Workshop
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– Final Panel Report –

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Introduction

The Western Pacific Fisheries Management Council manages bottomfish fisheries in Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. Annual stock status assessments are conducted and published each year, summarizing recent trends. Current assessment methods rely heavily on biased fishery-dependent data sets that lack information on important segments of the population, which together leads to uncertainty in stock assessments. Other factors influencing uncertainty include the small size of some of these fisheries with a high turnover of fishers, biological data gaps, and the recent establishment of no-take MPAs.

The objective of the workshop was to develop a plan to improve data collection and assessment methodology. Accordingly, the workshop (1) evaluated existing biological, oceanographic, and fisheries data as well as stock assessment systems relating to bottomfish resources of Hawaii and other U. S. Pacific island areas, (2) identified weaknesses in current assessment methods and supporting data, (3) reviewed alternative approaches for modeling and stock assessment, and (4) proposed a course of action to improve stock assessment methods and associated data collection. The workshop agenda is included as an attachment to this report (Appendix A).

Characteristics of the Bottomfish Fishery

Bottomfish fisheries may be regarded as consisting of meta-populations of fish associated with specific features or habitats, interconnected through larval dispersal but with little or no adult migration, though recent tagging studies in Hawaii question this assumption and suggests further investigations are needed.

The patchy nature of fish distribution has a number of implications:

- Fishing may occur sequentially. Signs of over-fishing (catch rate declines), and changes in population parameters (e.g. length / age at capture) will be difficult to detect unless detailed data are available at a high level of spatial and temporal resolution..
- Resource assessments:
    a) those based on yield-per-unit-area require accurate information on habitat distribution and attributes.
    b) the adequacy of production model estimates is somewhat constrained by the sequential nature of fishing operations.
- If patches of habitat (or seamounts) are severely depleted, recovery periods following over-fishing will be uncertain and unpredictable owing to variability in sources and levels of recruitment.
- Un-fished areas may act as sources of recruitment

Bottom fisheries exploit multi-species assemblages principally comprised of lutjanids, lethrinids and serranids. Members of these families are:

- Bottom dwelling carnivores (predators)
- Long lived (20 years plus)
- Slow growing (reported K parameter values 0.15 seamounts; 0.25 banks)
- Relatively low annual natural mortality rates (M 0.25 seamounts, 0.5 banks)
- Relatively low reproductive capacities

These characteristics make bottomfish species particularly susceptible to overfishing, particularly since the WPRFMC has approval to manage the fishery on an aggregate multi-species basis.

Banks and seamount characteristics

A number of different habitats have been defined based on the location of bank reefs, patch reefs, on irregularities on shallow parts of the sea bed. Unlike patch reefs, however, bank reefs tend to be deeper. They may occur both on the continental shelf and in oceanic waters (UNEP/IUCN, 1988). The banks are usually volcanic structures of various sizes. Coralline structures tend to be associated with shallower parts of the banks and reef- building corals are restricted to a maximum depth of 30 m. Deeper central parts of the banks may be composed of rock or coral rubble, sand or shell deposits. Outer bank slopes are generally steep. Banks thus support a variety of habitats, that in turn support a variety of fish species.

Fish distribution on banks is affected by substrate types and composition. Those suitable for lutjanids, serranids and lethrinids tend to be patchy, leading to isolated groups of fish with little lateral exchange or adult migration except when patches are close together. These types of assemblages may be regarded as consisting of meta-populations that are associated with specific features or habitats, interconnected through larval dispersal. From a genetic perspective, individual patch assesmblages may be considered as the same population for management purposes, but too little is known on exchange rates to determine how to distinguish discrete populations. Recent tagging results from Hawaii (presented by F. Oishi, agenda item 3.b.ii: opakapaka tagging data) suggests that fish migration may occur between isolated locations, but the extent to which this is the case requires further study.

Seamounts are undersea mountains, mostly of volcanic origin, which rise steeply from the sea bottom to below sea level (Rogers, 1994). On seamounts and surrounding banks, bottomfish species composition is closely related to depth. Deep slope fisheries typically occur in the 100-500 m depth range. A rapid decrease in species richness typically occurs between 200-400 m depth, and most fish observed are associated with hard substrates, holes, ledges or caves (Chave and Mundy, 1994). Lethrinids are not generally caught in deep water. Territoriality is considered to be less important for deep water species of serranids, and lutjanids tend to form loose aggregations. Mixing of adult populations of deep water snappers and groupers may thus be greater than for shallow water species occurring on banks. However, in the context of seamounts, it is considered unlikely that adult migration will occur between isolated seamounts.

Seamounts have complex effects on ocean circulation. One effect, known as the Taylor column, relates to eddies trapped over seamounts to form quasi-closed circulations. It is hypothesized that this helps retain pelagic larvae around seamounts and maintain the local fish population. Although evidence for retention of larvae over seamounts is sparse (Boehlert and Mundy, 1993), endemism has been reported for a number of fish and invertebrate species at seamounts (see Rogers, 1994). However, Wilson and Kaufman (1987) concluded that seamount species were dominated by those on nearby shelf areas, and that seamounts act as stepping stones for trans-oceanic dispersal. Snappers and groupers both produce pelagic eggs and larvae which tend to be most abundant over shelf waters. By contrast, larvae of *Etelis* snappers, are generally found in oceanic waters. It would seem likely that populations of snappers and groupers on seamounts rely to some extent on inputs of larvae from external sources.

Species characteristics

For management purposes the WPRFMC has defined an assemblage of bottomfish management unit species (BMUS) (see 2001 Annual Report). The fishery targets a multi-species complex consisting largely of lutjanids, lethrinids, and serranids. Such demersal species assemblages may show considerable overlap across habitat types but are clearly separated by depth. Hence the fishery is characterized by a substantial degree of technical interaction among the species components.

Distinct depth associations are reported for certain species of emperors, snappers and groupers (Sundberg and Richards, 1984; Dalzell and Preston, 1992) and many snappers, and some groupers are restricted to feeding in deep water (Parrish, 1987). The emperor family (Lethrinidae) are bottom feeding carnivorous fish found usually in shallow coastal waters on or near reefs, with some species observed at greater depths (e.g., *L. rubrioperculatus*). Lethrinids are not reported to be territorial, but may be solitary or form schools. The snapper family (Lutjanidae) are largely confined to continental shelves and slopes, as well as corresponding depths around islands. Adults are usually associated with the bottom. The genus *Lutjanus* (Bloch,1790) is the largest of this family consisting primarily of inhabitants of shallow reefs. Species of the genus *Pristipomoides* (Bleeker, 1852) occur at intermediate depths, often schooling around rocky outcrops and promontories (Ralston *et al.*, 1986b) while Eteline snappers are deep water species. Groupers (Serranidae) are relatively larger and mostly occur in shallow areas, although some occupy deep slope habitats. Groupers in general are more sedentary and territorial than snappers or emperors and are more dependant on hard substrata. In general, groupers may be less dependant upon hard bottom substrates at depth (Parrish, 1987). For each family, schooling behaviour is reported more frequently for juveniles than adults. Spawning aggregations may, however, occur even for the solitary species at certain times of the year, especially among groupers.

A commonly reported trend is that juveniles occur in shallow water and adults are found in deeper water (e.g., Parrish, 1987). Juveniles also tend to feed in different habitats than adults, possibly reflecting a way to reduce predation pressures. Not much is known on the location and characteristics of nursery grounds for juvenile deep slope snappers and groupers. In Hawaii, juveniles of *P. filamentosus* have been found on flat, featureless shallow banks, as opposed to high relief areas where the adults occur. Similarly, juveniles of the deep slope grouper *Epinephelus quernus* are found in shallow water (Moffitt, 1993). Ralston and Williams (1988), however, found that for deep slope species, size was poorly correlated with depth.

Multi-species fisheries and the interactions within them are complex and are not clearly understood. The effects of exploitation on an assemblage of species may be detected as alterations in the relative abundance of species in the management unit. Such changes in species composition may be due to fishing intensity, the relative catchabilities of the species (i.e., technical interactions), and the types of biological interactions among them. Competition and predation are considered the most likely forms of biological interaction in models of multi-species fisheries, and these may result in compositional changes due to a variety of factors, including changes in natural mortality, recruitment, and/or growth (e.g., May *et al*., 1979, in an example of a southern oceans fishery; Polovina 1984, in an example of a coral reef ecosystem).

In addition to biological interactions, technical interactions arise through mechanisms such as targeting (e.g., by depth) and gear selectivity. These can have a major influence on the species composition of a multi-species fishery (e.g., Polovina, 1986). Therefore, changes in species composition of the catch that arise from technical interactions should not be confused with actual changes in fish abundance within a multi-species community. For example, those species with higher catchabilities to a particular gear will be subject to greater fishing mortality and will be removed first, leading to a greater proportion of other species in the catch but not necessarily an increase in their abundance.

Models for the management of fish resources have principally been designed for single species. Polovina (1992) examined the applicability of a number of models to tropical multi-species fisheries. They include those applied to single species in parallel assuming no interaction, those which group all species together and treat them as a single species, and complex ecosystem box models incorporating all interactions. The more complex models require a large number of input parameters with significant requirements for data collection. One should thus determine if there is a need to rely on complex models, or whether simpler models are sufficient for assessments and management purposes.

In a study to investigate the effects of fishing on multi-species bottomfish fisheries in the Pacific and Indian Oceans, Mees and Rosseau (1996) used both observed and simulated data. Observed data indicated that no detectable multi-species responses occurred that could be related to biological interactions and fishing, but that significant detectable responses due to technical interactions did occur. The simulation study indicated that for ecosystems with similar characteristics, prey release (within the target BMUS) would be undetectable. While prey release was predicted to occur, starting around 5 years after the development of a new fishery, its magnitude was less than that observed in the available data.

These results indicate that, at least for the cases studied, single species and aggregate single species models can be useful in formulating management advice and can substitute for more complex ecosystem models that account for a multitude of interspecific interactions[1]. Even though the use of single species models in a multi-species context has often been criticized, we note that the performance of the multi-species assessment methods currently available have not been shown to be superior and are unable to provide precautionary reference points that are suitable for the management of mixed stock assemblages. Until this problem is solved, single species approaches will have to be relied upon to provide estimates of conventional reference points and for projecting stock dynamics. Overall, these findings support the approach taken by the WPRFMC to manage the bottomfish fishery as a single stock, at least into the near future.

Bottomfish Management Objectives

The management objectives of the Western Pacific Regional Fishery Management Council's bottomfish fishery management plan are to:

- maintain opportunities for fishing experiences by small-scale commercial, recreational, and subsistence fishermen, including native Pacific islanders
- protect stocks from environmentally destructive fishing practices
- improve quality and quantity of data available for fisheries management
- maintain year-round supply of fresh fish in Hawaii
- maintain a balance between harvest capacity and harvestable fishery stocks to prevent over-capitalization

Obviously, no single stock-assessment model can be used to determine how to best meet all these objectives, so the WPRFMC will most likely have to rely on several approaches to satisfy its goals.

Review of Existing Analytical Procedures

Analytical procedures used for assessing stock status and productivity vary among areas. All methods rely upon fishery-dependent catch-per-unit-effort (CPUE) as indices of abundance trends. The main statistics used as reference points are Spawning Potential Ratios (SPR) and MSY-based estimates from Dynamic Production Models.

Spawning Potential Ratio (SPR) Method

Species within the Main Hawaiian Islands (MHI) and in American Samoa have been assessed using SPR, which attempts to capture alterations in both relative abundance and reproductive capacity. Trends in relative abundance are assumed to be proportional to the ratio of annual fishery catch rate, ($CPUE_t$) to a base catch rate ($CPUE_0$), obtained by averaging catch statistics from the earliest fishing records in the MHI (1948-1952).

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[1] That study also developed guidelines for management of multi-species fisheries based on effort controls and closed areas. Management targets were set based on the most vulnerable or most valuable species (trade-off required) (see p. 161 of Mees and Rousseau 1996)

Thus, $CPUE_0$ is usually considered to represent the unfished stock size. Similarly, the spawning output of the stock is assumed to scale directly to the proportion of mature fish in the landings. Consequently, the proportion of mature fish $P_{m,t}$ is computed each year from data collected at the Honolulu fish auction, where fish are sorted into species lots. Auction lots tend to include fish of similar size and are labeled with the number of fish in the lot and the total weight of fish in the lot. Thus, it is a simple matter to transcribe and record all lot statistics and to compute the mean weight of fish in a lot. Moreover, Ralston *et al*. (1986a) showed that the variance of fish in an auction lot could be predicted with reasonable accuracy using species-specific multiple regressions that used the number of fish in the lot and the total lot weight as independent variables. They also demonstrated that the normal distribution produced a good approximation to the actual distribution of individual fish within lots. Then, given estimates of the mean and variance, the weight-frequency distribution of management unit species within lots is predicted and then summed over lots to estimate the annual weight-frequency distribution by management species and management area (MHI and NWHI)[2]. Given a knife-edge weight at maturity, for each species the proportion mature in year $\boldsymbol{t}$ ($P_{m,t}$) is then calculated from the composite annual size distribution of the catch. This procedure assumes that the size characteristics of pre-sorted lots has not changed over time. Also, we note that size-at-maturity was primarily estimated from studies in the NWHI. Given a $CPUE_t$ index for year $\boldsymbol{t}$ and $P_{m,t}$, SPR is just the ratio:

$$SPR = \frac{CPUE_t \cdot P_{m,t}}{CPUE_0 \cdot P_{m,0}}$$

where the base proportion mature $P_{m,0}$ was obtained from length-frequency samples collected in the Northwestern Hawaiian Islands (NWHI) from 1986-88, when stocks were believed to be lightly fished. The SPR method includes the following assumptions:

- fishery CPUE (lb/trip) is proportional to total stock size.
- species-specific maturity schedules in the assessed area are the same as those in the NWHI.
- maturity and fecundity are weight-dependent processes.
- maturity states in the commercial landings are representative of those in the population.
- CPUE averaged over the early development phase of the commercial fishery ($CPUE_0$) represents the unfished state and not sequential exploitation of small unfished stocks.
- Fishery catchability has not changed over the past 50+ years.

As usual, there are also assumptions about data-quality such that the actual catch and effort statistics accurately reflect the true values in the fishery.

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[2] The Ralston *et al*. 1986a regression equations used to estimate weight variance within auction lots should be updated.

SPR is a "data-based" stock assessment method used to assess the condition of the stock relative to an assumed unfished state. If the above assumptions hold, then it should be reasonable to apply this method as a data-based control rule in which SPR_t/SPR_0 is used to represent the current biomass-based (e.g., B_t/B_0) rules typically employed in U.S. marine fisheries management. There has been some recent research in the application of data-based harvest control rules in fisheries stock assessment (e.g., Hilborn *et al*., 2002).

The SPR approach is currently applied to five major bottomfish species in the MHI, NWHI, and American Samoa. Fishing effort that is used to compute $CPUE_t$ for MHI is based on species-specific targeted effort estimates. Within NWHI, area-specific SPR is calculated separately for the Mau and Hoomalu zones. Also, effort data used to compute $CPUE_t$ for NWHI is based on aggregate effort estimates rather than species-specific targeted effort. For Samoa, limited data precludes annual estimation of $P_{m,t}$, so these annual values are obtained from the MHI data (a practice in need of evaluation). SPR is not currently used to assess bottomfish fisheries in Guam and the Commonwealth of Northern Marianas Islands (CNMI).

Dynamic Production Model (DPM)

The second assessment procedure is a dynamic production model in which estimates of MSY are obtained fitting a biomass dynamics model to time-series CPUE data. Development of the DPM approach is necessary in order to satisfy MSY-based management procedures currently required under the Sustainable Fisheries Act (SFA). The basic production model employed is:

$$B_t = B_{t-1} + rB_{t-1}(1 - B_{t-1} / K) - C_{t-1}$$
$$C_t = B_t(1 - e^{-qE_t})$$
$$MSY = rK / 4$$
$$E_{MSY} = r / 2q$$

where B_t is predicted biomass in year t, C_t is the predicted catch, and E_t is the estimated fishing effort for year t. The basic assumptions behind the DPM are discussed in standard fisheries texts such as Hilborn and Walters (1992). Model parameters that must be estimated from the data are r – the intrinsic rate of biomass growth for the aggregate bottomfish stock (BMUS), K – biomass carrying capacity for BMUS, and q – fishery catchability for BMUS. An initial assessment was conducted using this approach in 1996 based on NWHI BMUS catch-effort data for 1987-1994. Attempts were made to reduce the overall number of model parameters for the BMUS stocks in the two NWHI areas. First, fishery catchability q was estimated independently based on fishing experiments. Adjustments were made to account for NWHI area-specific effects such total habitat area and observer-based estimates of local catch rates. Secondly, parameters were assumed to be common among areas. Uncertainty in the 1996 assessment employed bootstrapping estimates of q and catches and re-estimating model parameters.

Future Modeling Approaches

The development of assessment modeling efforts in the future relies on several factors including policy objectives, the biology of bottomfish species, spatial structure of the assemblages and the fishery, and regulatory/tactical tools available to implement management strategies on an area- and/or species-specific basis. In Hawaii the current management policy is based upon an aggregate BMUS and archipelago-wide MSY rule in which annual fishing mortality is determined by the depletion ratio B_t/B_0. Additional issues related to assessment modeling raised during the workshop include:

- Assess implications of meta-population structure on sustainable harvest.
- Evaluate whether the amount and placement of existing no-fishing zones is adequate for achieving fishery objectives (including maintaining fishing opportunities and harvest)
- Evaluate other types of spatial management options that might reduce fishing mortality on immature fish.
- Evaluate the need and use of fishery independent surveys and field experiments (acoustics, CPUE vs. abundance, changes in gear over time, direct measures of F)
- Impacts of recreational fishing on bottomfish populations and assessments

It was the opinion of most panelists that data either exist or could be obtained to address many of these objectives. Assessment models could then be formulated specifically to make use auxiliary data sources, or context-specific simulation models could be used to make projections given certain scenarios based on additional observations.

It is clear that immediate updating of historical assessments is needed to address SFA commitments. Therefore, the production modeling approach initially developed by Kobayashi (1996) should be updated to include more recent data sets, as well as additional information on individual species where possible. Although the only requirement under SFA is to assess the aggregate BMUS stock at an archipelago-wide scale, the panel recommends that assessments also be done at the species and zone scales where possible. This should provide a clearer indication of individual species status and the need for more detailed assessments, surveys, and possibly regulations.

Considerations for short-term assessment models

There are several ways in which to improve the existing DPM. Kobayashi and many other scientists have noted that carrying capacity parameters tend to be poorly estimated and prone to convergence failure. An attempt to minimize this problem involved “dynamically linking” carrying capacities among Hoomalu and Mau zones. However, this ignores the total habitat area in the two zones, meaning that carrying capacity could differ substantially if the two areas have unequal amounts of habitat. Re-scaling the model in terms of biomass density (e.g., biomass/habitat area) would make the carrying capacities comparable and a common parameter could be estimated. Another advantage of re-scaling the model in terms of density is to allow some general guidelines for estimating MSY/area for initial use in the outer islands, which currently have no formal assessment models. The DPM should be applied at both archipelago- and individual-zone scales and at BMUS and individual species levels. Although not necessary to meet SFA requirements, examining finer spatial- and species-level details addresses the well known fact that managing stocks on an aggregate assemblage basis is more risky than managing disaggregated units.

Similarly, the intrinsic rate of increase could be shared among zones as well. A simple literature search examining existing estimates of *r* (and possibly density *K*) for these, or similar species, should be performed. This information can be taken into account in a Bayesian estimation framework that includes informative priors on these parameters.

Panel Recommendations

The development of assessment modeling efforts in the future should rely on several factors, including specific policy objectives, the basic biology of bottomfish species, the spatial structure of the fish and fishery, and the regulatory/tactical tools available to implement management strategies on an area- and/or species-specific basis. In the Hawaiian Islands, with adoption of Amendment 6 to the bottomfish Fishery Management Plan (WPRFMC 2002), management by the Council is now based upon an aggregated total biomass stock (BMUS) and an archipelago-wide MSY rule in which annual stock status is monitored by calculation of a stock depletion ratio $CPUE_t/CPUE_0$. Stock status is assessed in relation to a minimum stock size threshold (MSST), which is equal to $(1-M)\times CPUE_{MSY}$ or, by proxy, $0.5\times(1-M)\times CPUE_0$, where M is the natural mortality rate [yr^{-1}]. This control rule currently relies on assuming that $CPUE_t \propto B_t$ and that maximum sustainable yield (MSY) occurs at one-half of virgin stock size, i.e., $0.5\times B_0$. If an analytically credible estimate of B_{MSY}/B_0 can be developed for the Hawaiian BMUS, using accepted stock assessment methodologies, the scientific basis of bottomfish management will be improved. The panel believes that potential modeling approaches that merit attention are non-equilibrium surplus production models, delay-difference models, and stock reduction analysis. Modern stock assessment textbooks (i.e., Hilborn and Walters, 1992; Quinn and Deriso, 1999) describe these approaches in good detail and should be consulted on the analytical specifics.

Short-term Recommendations

Data Collection

Efforts should be made to review, standardize, and improve some of the exisiting data collection programs. This is particularly important for the other islands in the Western Pacific Region (i.e., American Samoa, Guam, and the CNMI) with attention paid to developing appropriate data collection and sampling methodologies for the bottomfish fishery and for BMUS.

Biological data should be collected for key species in the catch, including length, weight, sex, maturity, and age, in order to determine important life history parameters. Life history parameters may then be used to develop indices of the status of exploitation, thus highlighting 'yellow light' situations requiring closer study and management action. In particular, rules of thumb have been developed specific to bottomfish (see for example Polovina, 1987; Mees and Rousseau, 1996). We also recommend that, where feasible, yield-per-recruit analyses (YPR) be performed for key species and that current levels of fishing mortality be compared with optimum levels of fishing mortality (F_{max} or $F_{0.1}$) to highlight 'yellow light' situations. Although YPR analysis is incapable of assessing the full effect of exploitation on fishery sustainability, it still provides a basic assessment of the total amount of fishing pressure experienced by a stock and is useful in determining the extent of growth overfishing.

To enhance accessibility, all of the data should be stored in a relational database. Ideally, it should be possible to relate all biological data to individual fishing events, or if from fishery independent surveys, data must be related to factors such as location and depth.

Modeling

Ralston and Polovina (1982) fit a multi-species surplus production model to data for MHI bottomfish stocks. That analysis used the State of Hawaii's commercial catch report data set, which is still the primary source of information used for status determinations of MHI bottomfish stocks (see above). In addition, estimates of MSY and associated reference points have been generated for the NWHI using 1987-94 data obtained from the limited entry fishery operating in that region (Kobayashi 1996). Given the importance of MSY-based reference points in status determinations of bottomfish, as specified in Amendment 6 to the Bottomfish FMP (WPRFMC, 2002), it is essential to update both of these models using as long a time series as possible.

Since 1948, commercial fishermen have been required to fill out and submit a C-3 report at the end of the month, mainly to record sales information. Nominally, this form includes a great deal of information on catch (species, number, weight), gear type, fishing effort (sometimes trip duration), fishing location (large areas), and sales. From 2002 onwards, the C-3 report was replaced by a monthly fishing report that holds more data (discards, fishing condition, bait), at higher levels of resolution (records by day, etc.). From 1994 onwards, fishermen in the NWHI were required to submit a different form (the NWHI trip report) that is still used today, mainly for the limited entry program. It also contains more detailed data than the C-3 report, but has a different format than that used in the MHI (bank fished, losses, etc.).

Consequently, the structure, resolution, and accuracy of the data varies across periods and regions. Ideally, these data series should be standardized to produce as long a time series of data for each of the two regions (NWHI and MHI) as is possible. There are, however, two major impediments to accomplishing this goal, especially for the MHI data. The first is that the C-3 report data set only contains commercial catch records, but recreational catches are believed to be considerable and may account for an increasing portion of the total harvest over time. If so, it is essential to approximate the unknown sport catch in some explicit manner, which could be accomplished by setting reasonable year-specific bounds on the harvest by the recreational fishery. This is a difficult problem to address because there hasn't been a recreational sampling program in place until recently. Nonetheless, it should be possible, at a minimum, to estimate the recreational catch for 2002 and 2003 from the new Hawaii Marine Recreational Fishing Survey (HMRFS) program now in place. One could then develop two distinct scenarios to represent "high" and "low" recreational catch histories, based upon the expert opinions of known individuals with a long association with the fishery. These two scenarios could be used to bracket a plausible range of what the historical level of recreational catch might have been. The Hawaii Small-Boat Fisheries Survey (Hamm and Lum, 1992) that was conducted during the 1980's is another important source of information that would likely be of substantial utility in estimating historical recreational catches.

The other major impediment to assembling time series of catch and effort data for the MHI is that fishing power most likely changed from 1948 to the present, which would alter the proportionality between fishing effort and fishing mortality, i.e., the catchability coefficient (***q***). Certainly the widespread availability of GPS today would greatly assist fishermen in relocating good fishing sites. Other technologies that would have been expected to have a marked influence on ***q*** were the widespread acquisition of fish finders and powered fishing reels. To increase the usefulness of the commercial catch report data from the MHI, we recommend that a workshop be held to address this issue. Specifically, the expert opinions of fishermen with a long history in the fishery should be documented to determine, at least loosely, the effect of these technologies on catch efficiency. From the collective knowledge of people familiar with the history of the fishery, it should be possible to craft a fishing power time series that could be used to adjust the effort statistics derived from the C-3 data set. To recognize and embrace the uncertainty in this endeavor it would be important to develop a range of scenarios bracketing the views of the participants.

Given these adjustments to the data (i.e., an explicit accounting for sport catches and changing fishing power), a non-equilibrium surplus production model (e.g., Prager 1994) could be applied to the full time series of MHI data and management reference points estimated. Given that management is based on the entire assemblage, a total biomass analysis should be conducted, in addition to species-specific analyses. We also see merit in the approach of Kobayashi (1996), who estimated ***q*** external to the model and linked the intrinsic rate of increase across banks in the NWHI. Moreover, it may be possible to conduct a formal Bayesian analysis if a reasonable prior distribution for catchability can be developed. Finally, we recommend that, in addition to surplus production models, different analytical procedures be explored and compared, including delay-difference models and stock reduction analysis (see Quinn and Deriso, 1999). Ultimately, the final outcome of this modeling exercise will depend on the skill of the analyst(s) and the reliability of the available data. A range of interpretations will emerge that will depend, to a great extent, on the various data scenarios and will lead to a range of possible "states of nature". A decision table analysis of these outcomes will then provide the Council with some idea of the overall uncertainty inherent in the stock assessment and the likely consequences of their actions.

Once the analysis is complete, efforts should be made to relate the estimates obtained with those stemming from the SPR analysis conducted annually by NMFS staff to ensure that the assessment results are coherent. Serious discrepancies should help identify where there is a need for changes in assessment procedures. Should the results appear coherent, the stock status information should be updated accordingly. It has been suggested that cpue in weight per unit of habitat might be a good index to use for these assessments.

Medium-term Recommendations

We offer a number of research suggestions for improving the scientific basis of bottomfish management by the Western Pacific Regional Fishery Management Council:

- The panel was impressed with the progress that has been made towards mapping bottomfish habitat in the MHI. The multi-beam acoustic surveys that are the basis of this work should be continued and the entire MHI survey data set entered into a GIS. As the mapping proceeds we recommend that scientists continue to associate areas of high bottomfish abundance with specific habitat variables that can be quantified with the multi-beam data. To date this has been accomplished primarily using observations from the submersible. A completed inventory, containing measures of habitat suitability, could form the basis for designing an efficient stratified-random fishery-independent survey in the future. In addition, creation of an inventory of bottomfish habitat in the NWHI should be considered.

- Nearly all of the basic life history parameters that are of special relevance to management are out of date and should be updated. In particular, the growth curves and reproductive rates of key species (e.g., *Pristipomoides filamentosus*, *Etelis coruscans*, and *E. carbunculus*) should be re-estimated to determine if compensatory adjustments in vital rates have occurred or whether spatial differences in demographic rates exist (e.g., between the NWHI and the MHI or among the Hawaiian Islands, American Samoa, Guam, and the Commonwealth of the Northern Marianas). This basic information is required to parameterize YPR models (e.g., Kirkwood, 2001) and the proposed operational model (see below).

- Implement a tagging program to determine the extent of movements, both within and between banks. The "Okamoto" study was deemed by the panel to be of considerable interest, given the repeated recaptures of certain individual fish and the apparent widespread movement of opakapaka across deepwater channels. This information would be of considerable use in evaluating the effectiveness of marine reserves in managing the bottomfish fishery, both in the Hawaiian Islands and elsewhere.

- Initiate a routine fishery-independent survey, with the intention of gathering unbiased relative abundance data that could be used to assess the extent of bias that exists in the MHI fishery-dependent CPUE data. Eventually, abundance statistics from a fishery-independent survey may even replace the commercial catch report CPUE statistic as the primary indicator of stock status. A baited-drop camera system has been designed and appears to have the good potential to provide *in situ* estimates of bottomfish abundance. Analysis of the data collected by this system should include both abundance and time of arrival to the baited station, possibly using the analytical technique described by Somerton and Kikkawa (1995). Survey sampling with the camera should be in accord with a stratified random survey, wherein habitat strata identified from the multibeam habitat mapping surveys are used to establish the sample frame (see above).

- It would be highly desirable to create an operational model of the fishery using existing information (larval movement, habitat distribution, growth, distribution, etc.) to simulate the dynamics of the entire assemblage. Once developed, a realistic operational model should be used to evaluate different potential approaches to stock assessment and management (e.g., marine reserves). Using simulated data with known characteristics that have been generated from the operational model, a variety of stock assessment approaches should be evaluated with respect to its ability to recover the essential properties of the simulated stock. An example of an operational model specific to bottomfish, which was used to study different management strategies, is given in Mees and Rousseau (1996).

- Two of the most important bottomfish species are known to occur in aggregations off the bottom (i.e., *P. filamentosus* and *E. coruscans*). Thus, it may be possible to estimate the overall distribution and abundance of these two species using traditional echo-integration hydroacoustic survey methods. A pilot study should be performed to evaluate the feasibility of this kind of an approach to estimating both relative and absolute abundance of these two species. Should this project prove promising, a recurring hydroacoustic survey would be a cost-effective means of monitoring the status of these stocks. Moreover, because the bottomfish management unit in Hawaii is a multi-species assemblage, difficulties in species identification, which often accompany echo-integration methods, may be of less importance.

Long-term Recommendations

The panel recognizes that a great deal of information needs to be collected to place bottomfish management on a strong footing. However, some of that information is difficult to acquire and will take years of research. However, research and technological developments completed elsewhere will no doubt benefit the management of bottomfish.

An important area of future research is to assess the meta-population structure of bottomfish stocks, which at the present time is completely unknown. Knowledge of the spatial structure of population sources and sinks, i.e., which banks are most critical to population persistence, is needed to effectively design spatial management schemes, including marine reserves. Specifically, given that a number of bottomfish stocks in the MHI are depleted while NWHI stocks are healthy, it is important to know whether spawners in the NWHI can generate substantial recruitment to the MHI. Answering this question is technically difficult, however, and will require a significant research effort.

Elsewhere in the world, grouper species are known to form spawning aggregations and to change sex, mediated through social interactions with conspecifics. These life history characteristics seriously complicate the management of grouper fisheries. The possibility that groupers aggregate to spawn in waters managed by the WPRFMC (i.e., Hawaii, American Samoa, Guam, or the CNMI) should be investigated and, if the existence of spawning aggregations is confirmed, time-area closures could be used to protect the spawning potential of the stock. Likewise, groupers are protogynous sequential hermophrodites (Shapiro, 1987) and present unique challenges to standard stock assessment models (Bannerot *et al*., 1987). There is a need to develop population models that capture the essential aspects of grouper biology and accurately gauge the effect of fishing on the persistence of grouper stocks.

Conclusions

The panel concluded that substantial information exists on the biology, distribution, and abundance of bottomfish stocks, especially in the Hawaiian Archipelago. However, much of the information appears to be fragmented and, as a consequence, it is not being used effectively to manage the resource.

Although, in many respects, the Western Pacific bottomfish fishery is smaller in scale than Pacific west coast fisheries, it is extremely complex owing to the unique nature of the species involved and their habitats, as well as the social systems characterizing the fishing community. Therefore, the panel strongly recommends that dedicated analytical expertise be brought to bear on: (1) synthesizing existing information and data sources into a more complete and accessible form, (2) developing a range of alternative stock assessment methods that range from simple, aggregated models to more detailed ones that include species- and perhaps area-specific biological and fishery parameters, and (3) developing operating models that represent the range of complexities involved in bottomfish biology and fisheries. The ultimate aim in developing these models of the bottomfish fishery should be to expose the strengths and weaknesses of the current assessment and survey methodologies, and to provide guidance on research to improve them.

In addition, the panel recommends that one person be given the responsibility of carrying out the recommendations of this report and be given the resources to accomplish the job, i.e., coordinating and centralizing data collection, initiating new resource suveys, improving stock assessments, gathering basic life history information, and conducting the other activities recommended above. This would likely be a more cost-effective solution than having several individuals work in a piece-meal fashion on various issues, since the lead person in charge can ensure that all the work is coordinated, establish priorities, and be aware of the intricacies, deficiencies and limits of the information used. From our experience, we believe that the activities recommended above amount to multiple man-years or work before comprehensive assessments can be conducted, and proposed management scenarios can be evaluated in a scientifically credible fashion.

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Appendix A. – Workshop agenda

Bottomfish Stock Assessment Workshop
January 13-16, 2004

Western Pacific Regional Fishery Management Council
Council Office
1164 Bishop Street
Honolulu, HI 96813
(808) 522-8286

Tuesday, January 13, 2004 9:00 a.m. - 12:00 noon

1. Opening
    a. Workshop Goals — Robert Moffitt
    b. Expected Deliverables — Robert Moffitt
    c. Review agenda — Robert Moffitt
    d. Appointment of Rapporteurs — Robert Moffitt
2. Review of Commercial Fishery — Mark Mitsuyasu/Walter Ikehara
    a. Recent events impacting fishery in WPR including a chronology of regulatory events (i.e. limited entry programs, HI Bottomfish RFA)
3. Review of Data Collection
    a. Fishery Dependent Programs
        i. Catch Reports, etc. (Commercial) — Walter Ikehara
        ii. Creel Surveys (Commercial/Recreational) — David Hamm
        iii. Observer Program — Lewis Vanfossen

Tuesday, January 13, 2004 1:00 p.m. - 4:30 p.m.

3. Review of Data Collection
    b. Fishery Independent Programs
        i. Submersible/bait station — Chris Kelley
        ii. Opakapaka tagging data — Francis Oishi
        iii. RAIOMA — Robert Moffitt
        iv. Acoustic studies — Whitlow Au
    c. Habitat Mapping & Charaterization — Chris Kelley
    d. Oceanographic/Satellite Data — Lucas Moxey
4. Sources of Data
    a. Quality of data (in matrix based on Admin. Report)
    b. Biological Data

Opening Reception to follow in Council Office

Wednesday, January 14, 2004 9:00 a.m. - 12 noon

5. Current Assessment Methodologies — Robert Moffitt
    a. Bottomfish FMP
        i. SPR
        ii. New plans for over fishing/control rules

6. Population Models & Survey Concerns/Shortcomings — Gerard DiNardo
   a. Using assemblages vs. species in model parameters
   b. Data Collection

Wednesday January 14, 2004 1:00 p.m. - 4:30 p.m.

7. Analytical Tools & Approach Methodologies — Panelists
   a. What are other people doing in terms of assessments?
   b. Outcomes of Deep Reef Fisheries in New Zealand

Thursday, January 15, 2004 9:00 a.m. - 12:00 noon

8. Model Development & Data Collection Discussion — Steve Ralston
   a. What kind of model do we want/need?
   b. What kind of model can we develop w/information we have?
   c. What other information do we need?

Thursday, January 15, 2004 1:30 p.m. - 4:30 p.m.

9. Generation of Report — Robert Moffitt
   a. Panel begins developing report

Friday, January 16, 2004 9:00 a.m. - 12:00 noon

10. Report from panel
    a. Review by Participants
    b. Discussion
    c. Comments

Luau at Waikiki Aquarium 6:00 p.m. - 9:00 p.m.