Preliminary Report on the Management Implications and Effectiveness of Potential Bylaws in the Kaledupa Fisheries, Wakatobi Marine National Park Indonesia

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Operaton Wallecea
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Overview

The Wakatobi marine National Park ranks as one of the highest priorities for marine conservation in Indonesia because of the diversity of species, reef condition, and the opportunity to protect such a large network of Marine Protected Areas. Like many of Indonesia's marine environments, Wakatobi National Park's (Figure 1) diverse coral habitats are threatened by overfishing and destructive fishing practices.

Figure 1: The main islands that form the Wakatobi archipelago: Wangiwangi Island, Kaledupa, Tomea, and Binongko. The small white box in the inset shows the location of the archipelago.

One of the main problems on Indonesian coral reefs is over-fishing by local people using small scale or artisanal techniques. Until recently artisanal fishing has been regarded by the Indonesian government as too small scale to have any significant impact on reef fisheries. As a result there has been no legislation to restrict fisheries on coastal reefs and in many parts of the archipelago the reef fishery has been seriously impacted. An example of this is on the reefs around Kaledupa Island in the Wakatobi Marine National Park, SE Sulawesi in Indonesia. Scientists and university students as part of annual biodiversity and fisheries surveys funded through Operation Wallacea have studied these reefs and the fishery since 1996. The results from these surveys demonstrated a fishery that was in serious decline with average catch per unit effort at 10% of levels in other parts of the Pacific and evidence of some species being commercially extinct.

The Darwin Initiative funding was obtained to demonstrate how a reef fishery could be managed sustainably by using financial incentives. The advantage of using Kaledupa Island was the long-term presence of Operation Wallacea at the site to provide the monitoring data to assess the effectiveness of the scheme, the support (with powers devolved from central government) of the Wakatobi government in implementing the political changes needed, the existence of a strong fishers based NGO and a strong desire from the local fishers to manage their own fishery and stop the decline in their incomes.

The proposed scheme works by registering all the fishers and their boats on Kaledupa. This registration has proved popular with Kaledupan fishers since it prevents fishers from other islands utilizing their reefs. Once the scheme is fully implemented though the objective is to reduce overall fishing effort to ensure the fishery begins to recover by offering businesses for up to 30% of the fishers in exchange for surrendering their licences. The fishers coming out of the fishery would therefore only do so if the businesses created more income than continuing to fish the reefs, whilst those that remain in the fishery then have a licence with a value equal to that of the income created from the businesses for those ‘selling’ their licenses. These remaining stakeholders would be allowed to trade the licences amongst those on Kaledupa or use them as collateral for raising funds. This scheme needs local byelaws introducing by the Wakatobi government and a Kaledupa Fishers Forum created to actively manage the reef fishery. A weekly fishery monitoring program has been implemented to provide data by which the Forum can take the necessary decisions to maximizes the sustainable yield from the reefs. The goal of this report is to analyze the data sets and to model the effects both on fishers and on recovery of the fishery of adopting various byelaws.

The Fishery

Currently the fishery in The Wakatobi and specifically Kaledupa is characterized by subsistence and artisanal fisheries where upwards of 80% of the catch is consumed the day it is landed (Kaledupa Fisheries Report 2008). Local fishers report that catches have been declining in recent years, both in amount and size of the catch. Local consensus reports that there are three reasons behind the declining trend of fish-catch in this region: (a) The high effectiveness of fish-gears; (b) The increasing number of fishers; (c) habitat degradation.

Catch composition analysis highlights the dependence of the fishery on four main families, Lethrinidae, Mullidae, Scaridae and Siganidae. Although there is geographical variability in the abundance of particular species caught by each technique, where there are sufficient samples to be confident in the data, 2 species from Siganidae, 2 species from Mullidae, 5 from Lethrinidae and a wide variety of Scaridae form a large proportion of many catches (Kaledupa Fisheries Report 2009).

Common species in the catches that mature at sizes greater than 20 cm are being caught before they have the opportunity to spawn. In fact, 82 % (for July 2007- May 2008) and 87% (June 2008- April 2009) of all species that mature at a size greater than 20 cm are caught before they are mature. In general, the largest species such as groupers and trevallies, precisely those species that are highly sought after by divers, recreational anglers and fishermen, are caught many years before they spawn. For several of the larger species, not a single mature individual was recorded in catches from July 2007- May 2008 nor from June 2008- April 2009.

Historically the reef fish communities of Indonesia were exploited by small populations that fished in artisanal manners. Reasons for the earlier light exploitation of the resource included the small and poor human population of the eastern islands, which limited the local demand for fresh or dried fish. Fresh fish was supplied by subsistence and artisanal fisheries that landed catch daily. Boats that went further offshore dried their catch aboard or on small islands and sandbanks. A decade ago there was no post-harvest cold storage chain from boat to distant markets.

Data Summary

From July 2007 until May 2008 Fisheries Monitors employed as part of the Darwin Initiative recorded 161,000, and 36,600 fish caught from June 2008 to April 2009 by fishermen in 9 villages on Kaledupa. Note that the difference in the number of fish recorded corresponds to the number of individual monitor days, which were three times as many during the 07/08 season as the 08/09 season. Catch Per Unit Effort (CPUE) was calculated for each fishing technique and this, along with analyses of species composition, percentage maturity, and percent change from previous years were used to assess the health of the reef fisheries around Kaledupa (Kaledupa Fisheries Report 2009). Specific data collected includes; Technique, Mesh Size, Length (of gillnet or line), Soak Time, Village, Habitat, species name, species length, total weight of the catch, weather date and area. The Kaledupa Fisheries Report from 2009 noted that the CPUE has held steady or declined from 2008 in multiple areas and in general is much declined from the limited sampling in 2005(Kaledupa Fisheries Report, 2009).

Main Species

Although there are over 500 individual species in the catch records many of these species are caught only rarely, the data analysis and potential bylaws are therefore based on what is termed the “Main Species Complex” as defined in the Kaledupa Fisheries Report 2009 (Table 1). These are the species which are the most highly sought after by divers, recreational anglers and fishermen, and are caught many years before they spawn.

Main Species Complex	
Barracuda	Giant seapike
Bigeye trevally	Giant trevally
Blue-tailed mullet	Golden trevally
Blue barred parrot fish	Malabar grouper
Blue trevally	Milk Shark
Bluefin trevally	Rainbow runner
Crocodilian longtom	Silver trevelly
Double-spotted queenfish	White-Lipped Catfish
Flathead mullet	

One of the assumptions in this report is that the data analysis and potential bylaws modeled on the main species complex is transferable to other species. That is to say that a 10% reduction in gillnet effort on the main species would also result in a 10% reduction of effort on all other species. Initially apparent is the fact that the majority of the catch is immature (Figures 2 & 2a). Across all species and gears the majority of the catch measures less than 35 cm (Figure 3).

Note that Figures 2 and 2a reflect the not only the data that were collected and my not be represented of the entire catch. Fishery monitors typically sample 10-20% of the boats as they come ashore. Furthermore the influence of (one or more) strong year classes may substantially alter the length frequency analysis and catch curve.

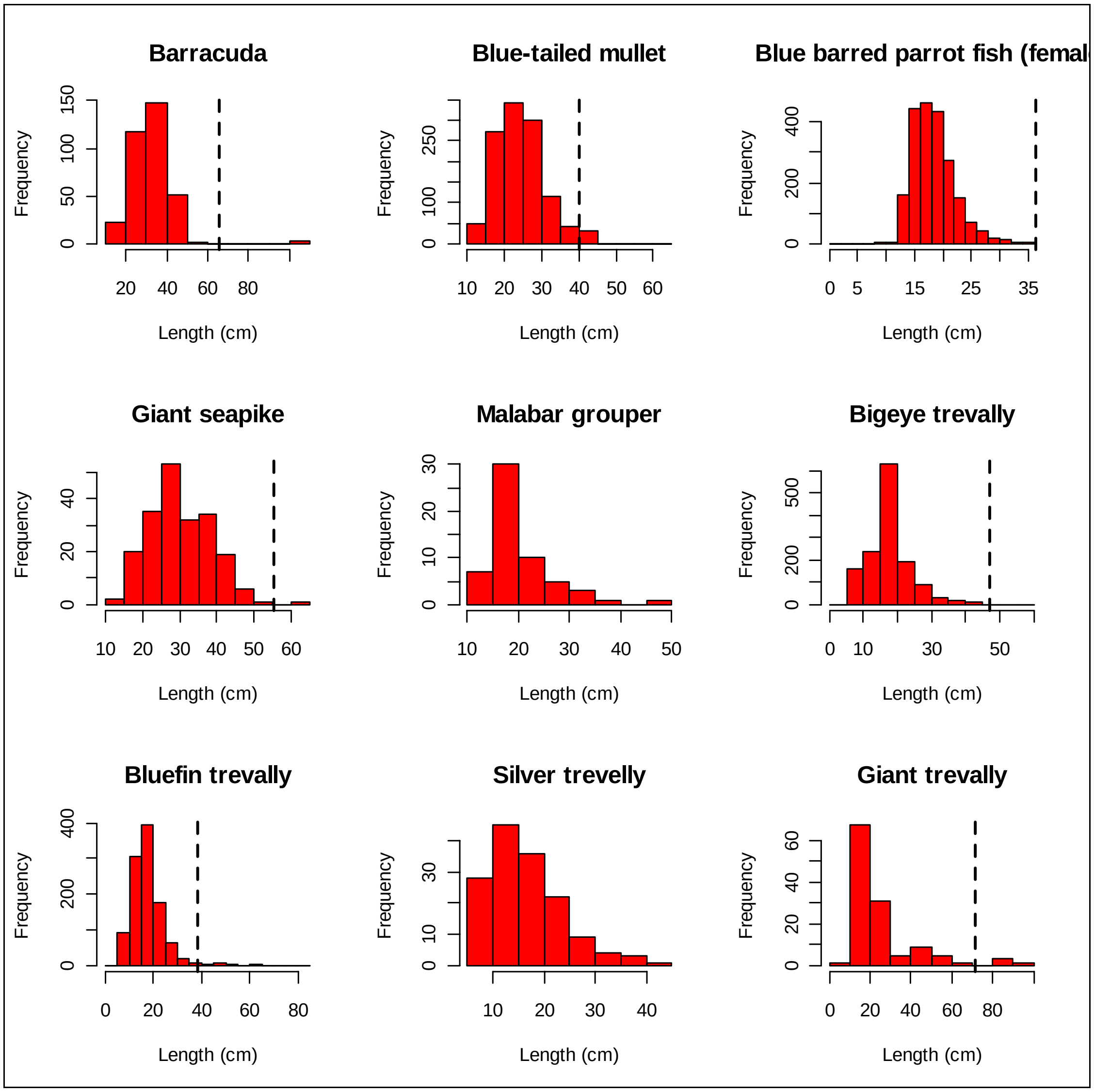

Figure 2. Length Frequency plots of selected important fish. Dotted vertical lines represent the size at maturity, plots without these lines have high size at maturity.

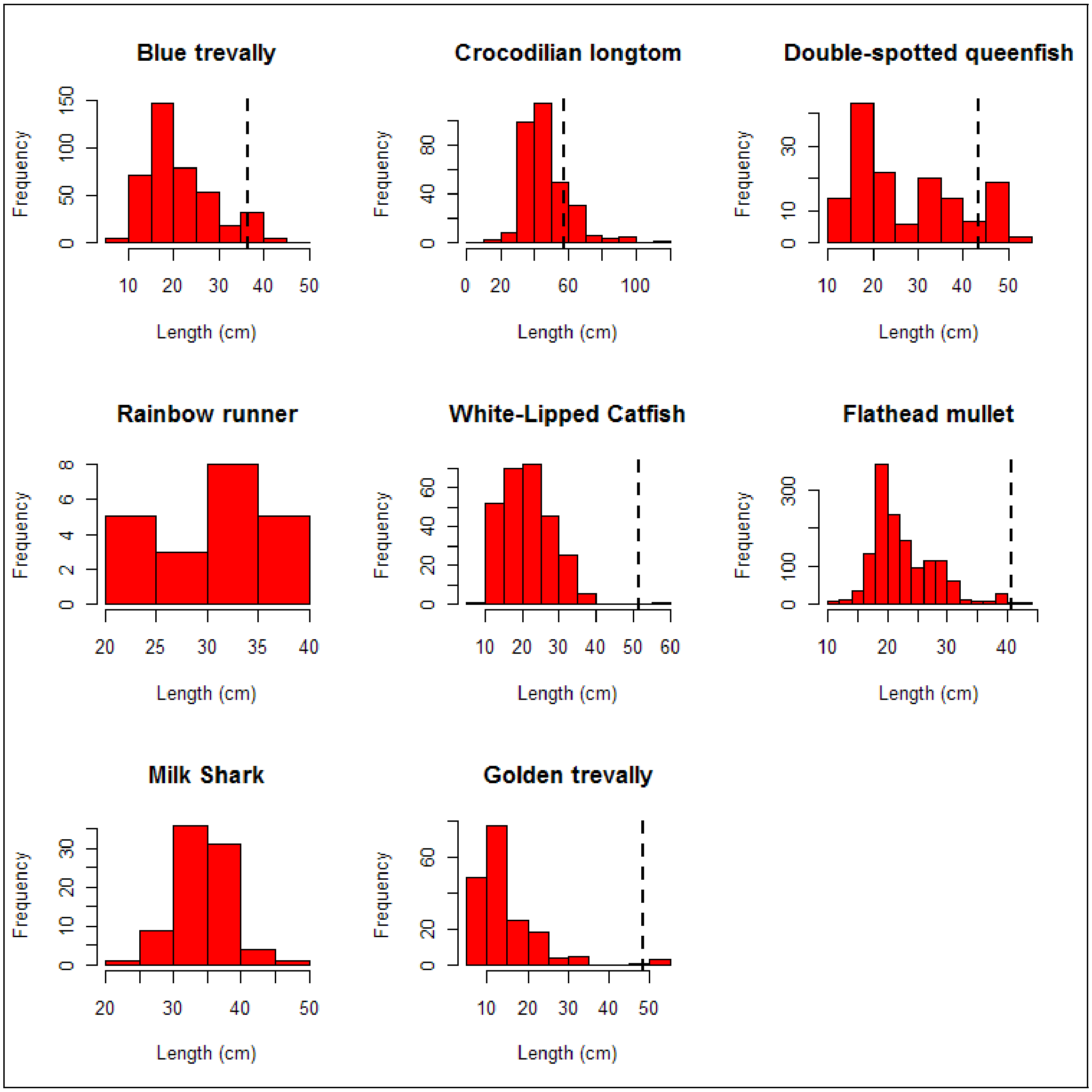

Figure 2b. Length Frequency plots of selected important fish. Dotted vertical lines represent the size at maturity, plots without these lines have high size at maturity.

Current and Potential Management Strategies

Historically there have been no specific management strategies for fisheries that are generally considered subsistence/artisanal fisheries. This means that there is neither a limit on the catch nor minimal size limits for any individual fish. Management options and reference points investigated in this report revolve around the influence of potential fishery bylaws on the recovery of the fishery and the resulting effects of the bylaws on the economy. Maximum Sustainable Yield (MSY) and other fishery reference points are straight forward to calculate however due to the inaccuracy of the data and the model instability these measures are considered to be relative and not absolute. The effectiveness of potential management actions is evaluated in regards to the status quo, ie what will the effect of a particular management action be in regards to the current situation.

Although there is currently little to no enforcement of management options, the potential bylaws examined here rely on the acceptance of local communities. A democratic process by which each village would have its own forum consisting of a representative from local government (BPD) and all the fishers from that village to meet regularly to discuss ways in which the fishery on the local reefs could be managed was organized in 2008. A representative from each of the village Forums would then be elected to a Kaledupa Fisheries Forum to work alongside the sub-district heads (Camats), and police, army and Park ranger representatives. This process was followed with all 25 villages and 2 sub villages completed by November 2008. In each village a Village Fishers Forum has been formed and a representative elected to the Kaledupa Fishers Forum.

The consultation process obtained views from each of these Village Fishers Forums on potential fishery byelaws that would have general support. The results of this consultation in the main villages and with partner organizations (eg The Nature Conservancy, WWF and Wakatobi National Park) are outlined in appendix 4 of the 2009 Darwin Annual Report. Specifically this process resulted in the recommendation of the following byelaws:

1. Ensuring the reef zonation uses proposed by the Wakatobi National Park are implemented in full. This was taken further by some communities who wanted village boundaries but this would cause issues with the Bajo communities who would then be excluded from most of the reefs.

2. Ensuring that any new fish fences constructed need the prior approval of the Wakatobi Government and National Park authorities.

3. Ensuring existing fish fences have a cod end mesh of 1.5 inches (knot to knot), the leader sections closest to the cod end have a mesh of 2.5 inches and the distal end of the leader fences have a mesh of 2 inches.

4. Ensuring that all gill nets used have a mesh of 1.5 inches and a maximum length of 50m and depth of 1.3m.

5. Ensuring that all bubu traps are licenced by the Wakatobi Government and a maximum number of licences agreed for usage around the Kaledupa reefs.

6. Ensuring all middle-men selling fish to collector ships visiting the Kaledupa area are licenced by the Wakatobi Government. This came about because a number of the villages were concerned about outside fishers who mainly come for the species that can be sold to middlemen.

The effects of these proposed byelaws on the Kaledupa fishery and the impact on fishers of their introduction are currently being modeled based on the data collected on all the gear being used in Kaledupa and the weekly fisheries monitoring exercise. In addition legislation for a zonation plan has already been passed.

Analytic approach to modeling potential bylaws

Potential bylaws do one of two different things, bylaws that restrict the gear size affect the age of entry into the fishery, bylaws that limit number of traps or fences (or length of gillnet) reduce the overall fishing pressure and hence the fishing mortality (F). Bylaws that are oriented at issues of zonation or licencing are not currently modeled. However it is reasonable to assume that the zonation/licencing bylaws would reduce fishing effort, potentially having the same effect as direct effort reduction. Changes in Yeild per Recruit (YPR) and spawning stock biomass per recruit (SSB/R) were explored under different levels of fishing mortality and selectivity.

Length at age and weight at age were calculated for each species, using published data and the von Bertalanfy Growth Formula (VBGF). This data was then used to define a selection pattern, by gear type for the species. The age at 50% selection/vulnerability was taken as the mean length by gear type. Then proportion mature was defined based on the values from the literature. The natural mortality was taken from literature values and current fishing mortality was estimated through catch curve analysis.

Spawning stock biomass per recruit and yield per recruit were estimated based on the estimated selection, weight, and maturity functions. The effect of gear size restrictions was modeled as a change in these values based on the age of entry into the fishery. YPR was compared under different levels of fishing mortality.

Entry into the fishery was modeled based on the available length data, in situations where age of entry into the fishery was needed age was calculated based the VBGF. Growth parameters for each species in the main species complex based on available literature and when needed obtained from FISHBASE (www.fishbase.org) to estimate growth parameters for the VBGF:

$$L_t = L_\infty(1 - \exp[-K(t - t_0)]) \quad (1)$$

where L_t is the fork length of the fish at age t, L_∞ the theoretical length at age infinity, K the intrinsic growth rate and t_0 is the theoretical age at length zero. Re-arrangement of the VBGF yielded the age of entry into the fishery based on the median length recorded per species/gear combination.

Yield Per Recruit

Yield-per-recruit (Y/R) and spawning stock biomass-perrecruit (SSB/R) assessed using the model of Beverton and Holt (1957). The yield per recruit function was defined as

$$Y/R = \sum_a \frac{F_a}{M_a}(1 - e^{-Za}) w_a e^{-\sum_{a'<a} z_{a'}} R$$

<u>Effect of Bylaws Results</u>

Mesh Size Analysis.
Changing mesh size is only effective for some species because it fish are not uniformly caught by the small meshes (Figure 3). For example, the data shows that the milk shark (top row middle panel Figure 4)is caught mainly by 2.5 inch mesh, reduction in gear size would not affect the catch composition nearly as much as it would the double spotted queenfish (bottom right panel), Mesh size restrictions would change the length frequency of the catch, allowing more smaller fish to mature before entering the fishery.

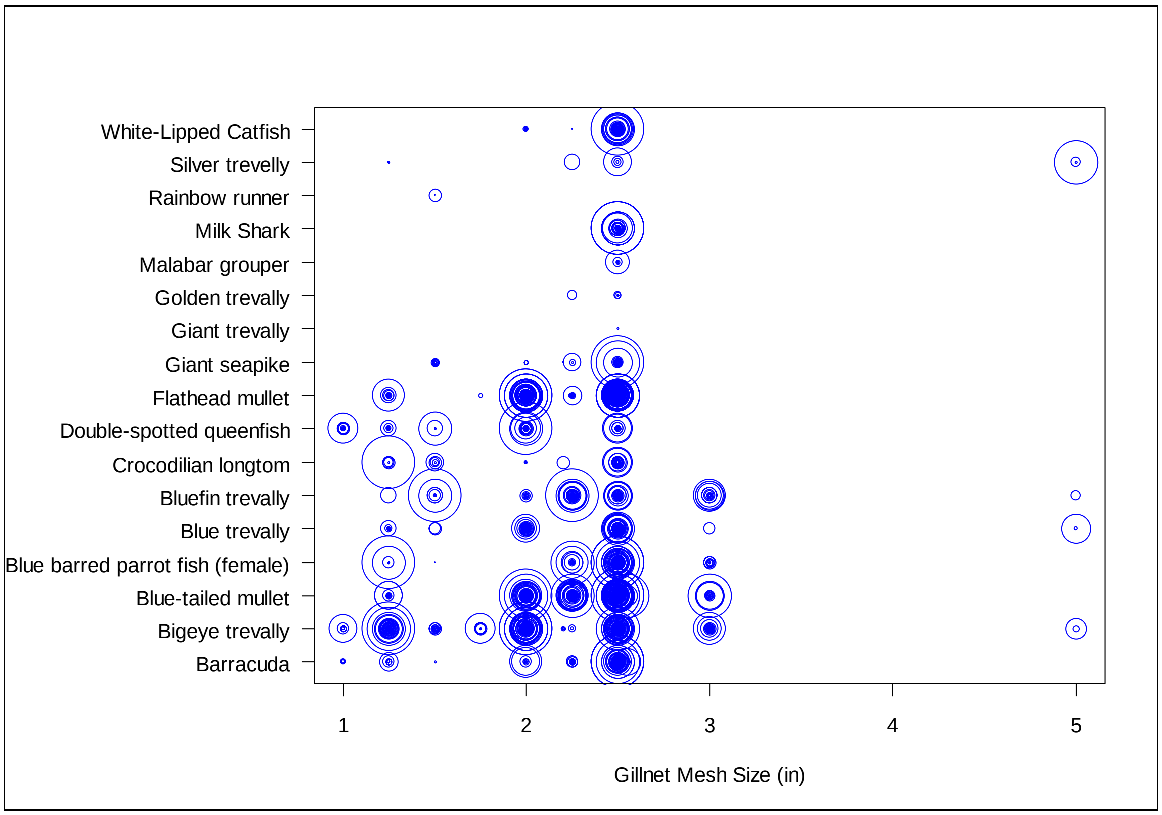

Figure 3. Catch by gillnet mesh size with points scaled by frequency, the larger the circles the more prevalent the catch per gillnet size.

Minimum mesh size was calculated for each species, to assess the impact of gear size restrictions, ie, which fish get caught by smaller mesh sizes (Figure 3). Changes in Mesh size would affect the following species the most; Flathead Mullet, Double-spotted Queenfish, Crocodilian longtom, the Bluefin Trevally, Blue Trevally the Blue Barred Parrot Fish, the Blue tailed Mullet the Bigeye trevally and the Barracuda. Other species of interest do not have catch records associated with smaller (<2 inches) gear. The next step was assess whether length was associated with mesh size, conditional analysis plots (Figure 4 and 5) highlighted the species for which there was a positive correlation between length and mesh size. Absence of a positive correlation between length and mesh size may be a result of low catch (or abundance numbers). For species without positive correlation between mesh size and length, reduction in fishing effort may be the best method of improving the stock status, as smaller fish are already.

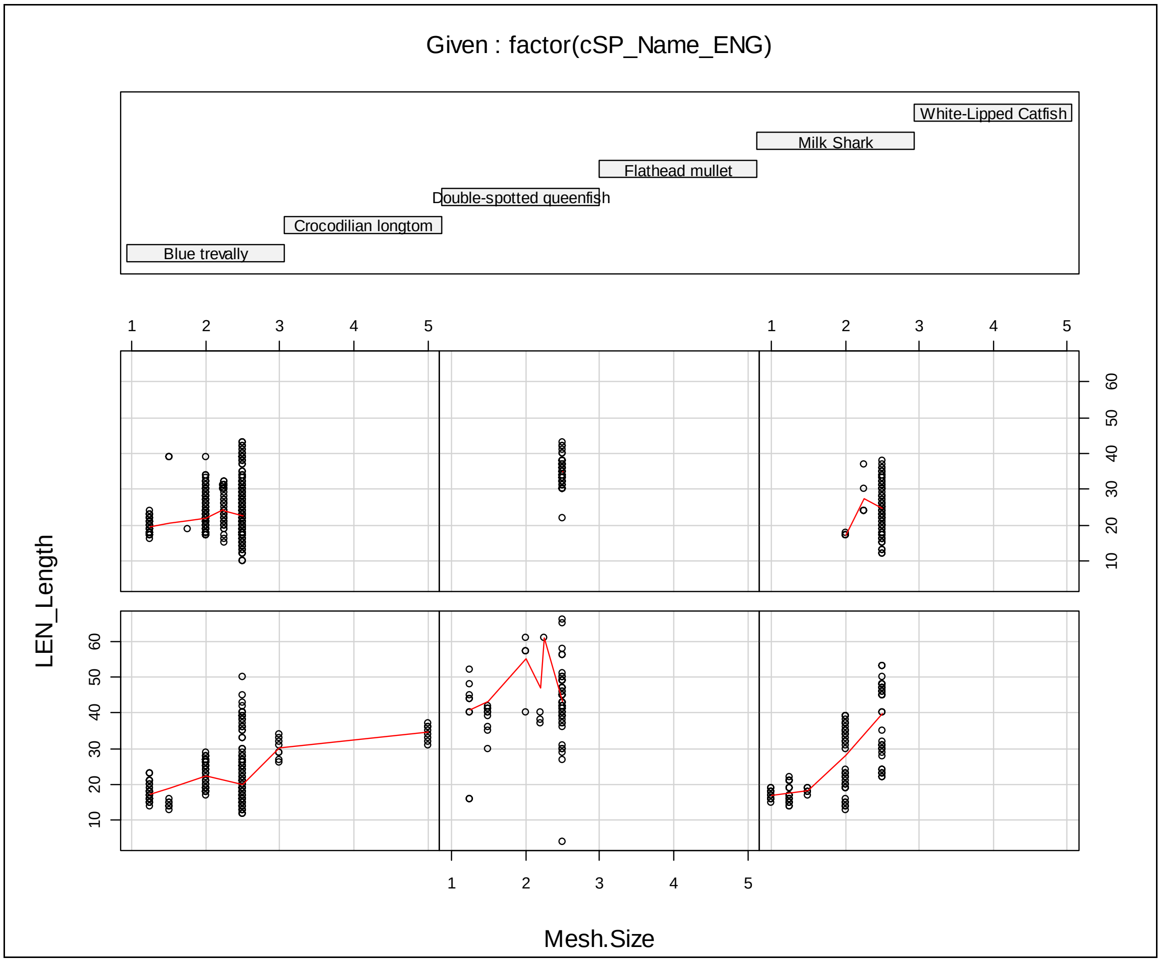

Figure4. Conditional plot of Length to Mesh Size, by species. Panels are indexed from lower left to upper right by the given variable on the top.

Restrictions on mesh size change the length selectivity of the fishery, to associate length with entry into the fishery a selectivity function (Quinn and Deriso, 1999) where alpha is the rate of change in selectivity by ages and delta is taken to be equal to 1 ((Quinn and Deriso, 1999). The age at 50% vulnerability (a_{50}) was taken to be the estimated from the mean length by species across all mesh sizes.

$$S_a = \frac{\delta}{1 + e^{-\alpha^*(a - a_{50})}}$$

The change in gillnet mesh size affected the age of entry into the fishery and hence the selectivity patterns (figure 6). Figure 6 shows three calculated selectivity patterns based on minimum mesh sizes of 1.5, 2, and 3 inches for Bluefin Trevally. This analysis assumes that even with a minimum mesh size of 1.5 inches, there will be substantial (equal to current levels) of fishing with larger mesh size gears.

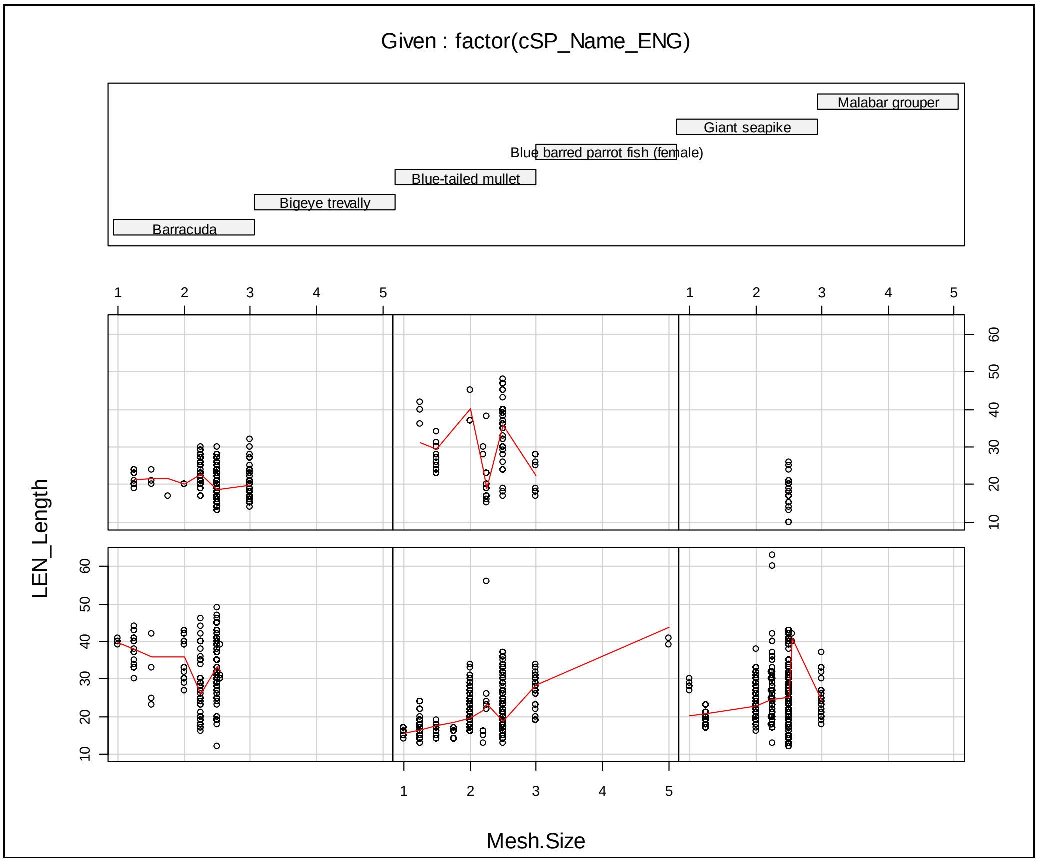

Figure5. Conditional plot of Length to Mesh Size, by species. Panels are indexed from lower left to upper right by the given variable on the top.

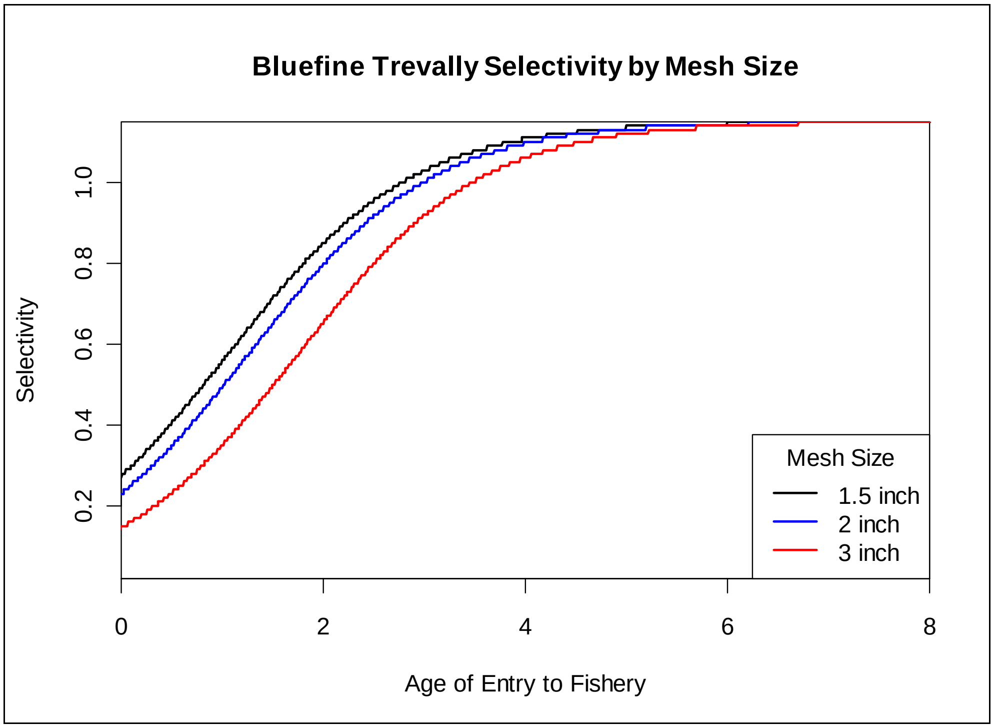

Figure 6. Selectivity curves for Bluefin Trevally

The selectivity of the different mesh sizes is evident in the empirical density plots, which show that bigger fish are generally caught by larger gear, as evidenced by plotting the length as a function of the mesh size (Figure 7).

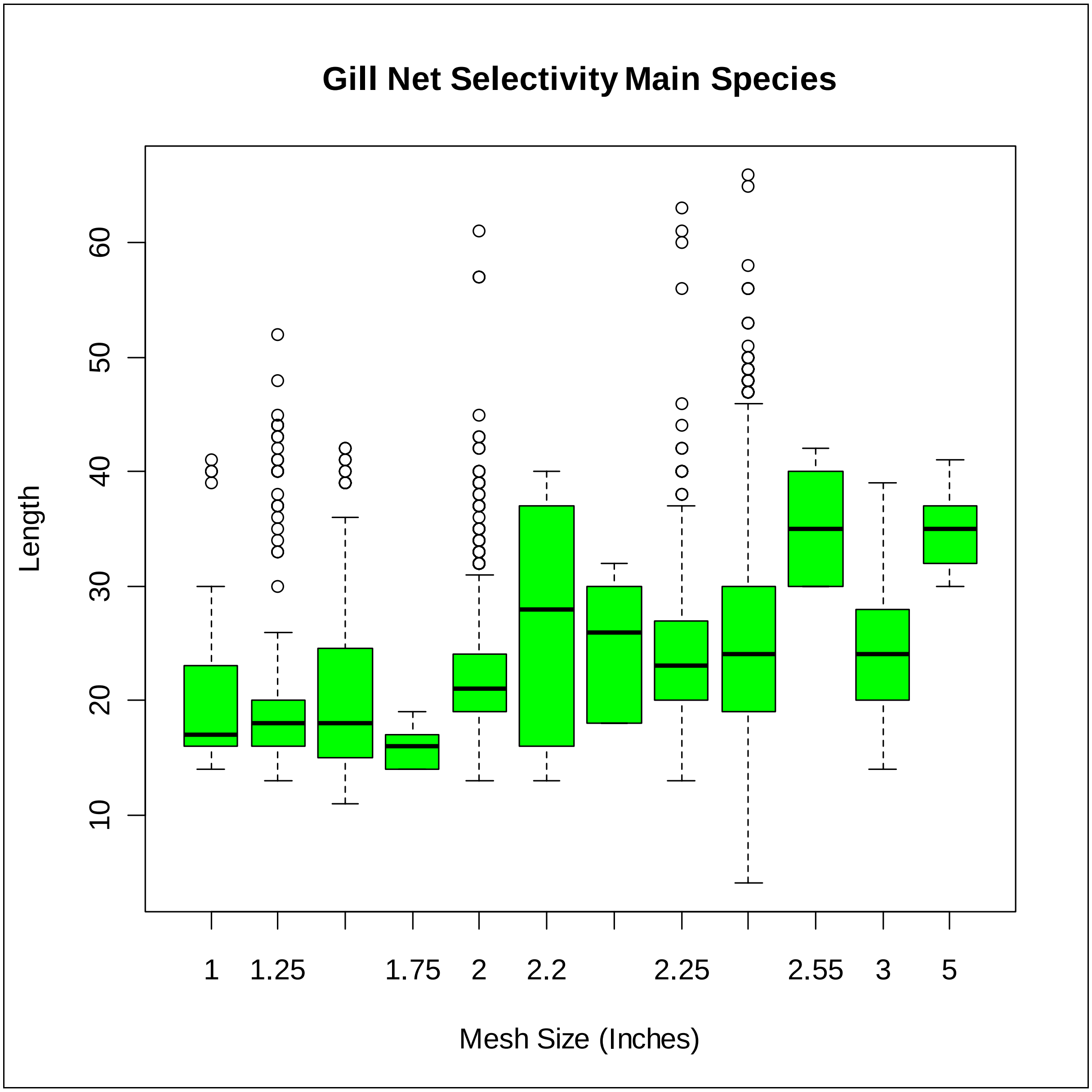

Figure 7. Fish length by gillnet mesh size for Kaledupa fisheries 2007-2009.

Selectivity patterns based on individual minimum mesh sizes were then applied to a yield per recruit and spawning stock biomass per recruit analysis to estimate the effect of changing mesh sizes. The results for Bluefin trevally are shown in Figure 8 and Table 2. Maximum sustainable yield, fishing effort at maximum sustainable yield and the fishing effort that would lead to crash of the population were calculated for Bluefin Trevally. It is evident that with smaller mesh size the yield is lower and the potential to overfish the stock is much greater, as evidenced by the yield per recruit curves in Figure 8.

Table 2. The impact on MSY, Fmsy and Fcrash of three different mesh sizes, gillnet fisheries Bluefin Trevally only.

Mesh Size	MSY	Fmsy	Fcrash
1.5	144.8	0.70	1.05
3	187.1	0.95	1.45
5	287.5	1.60	>2.0

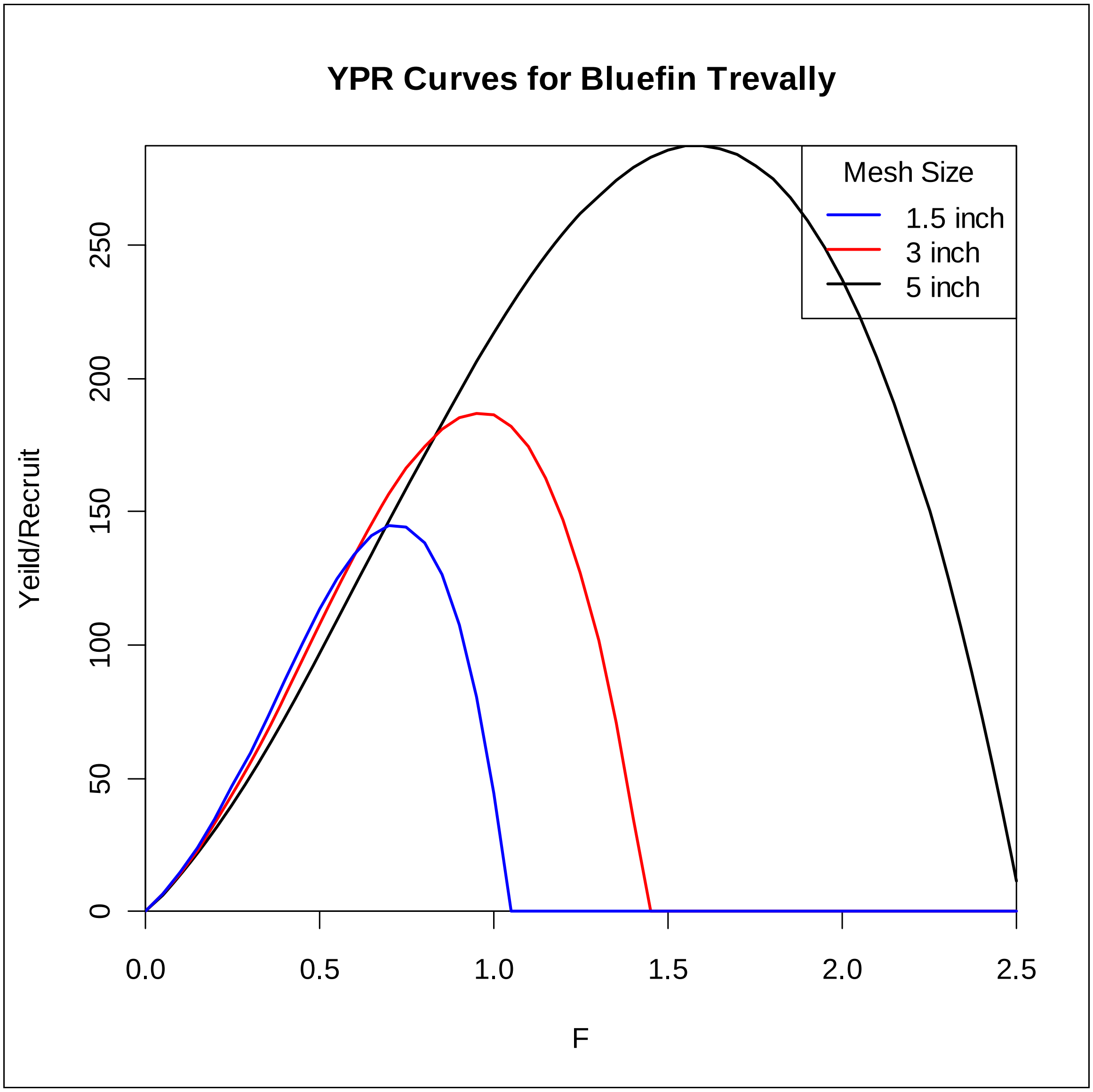

Figure 8. Yield per recruit

Discussion – management scenarios

By increasing the length (age) of entry into the fishery we are allowing for a more productive stock, therefore shifting the YPR and Fmsy higher, this is the cumulative affect of letting smaller fish mature. Increasing the Minimum mesh size on gillnets and fish fences is the first step towards allevating fishing pressure on the younger fish.

The life history of many of the fish analyzed in this report are typical of medium to large growing reef fishes that are fast growing early in life and have a relatively high reproductive potential. Unfortunately many of these species reach maturity only after multiple (sometimes just a few) seasons in which they are at least partially vulnerable to the multiple gear types being used in the area. This has significant implications for management of the all species as their particular importance in subsistence, commercial and recreational fisheries increases. The extensive use of reef habitat by juveniles and the relative ease of access for fishermen to these habitats make many of these species vulnerable to over fishing.

In the Kaledupa fishery were historical data on catch and effort covers only a few years management scenarios need to be conservative to establish sensible reference points that will not provide undue risk of overexploitation and simultaneously prevent excessive loss for fishermen in the area. Traditionally, maximizing yield by fishing at F_{max} has been a theoretical tradeoff between the economic loss and potential overfishing, hence a good management reference point. However MSY and its associated fishing mortality assume a constant recruitment that is independent of spawning stock size, and *Fmsy* easy to surpass, thus it has been seen as an imperfect solution (Gabriel and Mace, 1999). Alternatively more conservative $F_{0.1}$ has been advocated by Gulland and Boerema (1973) as a reference point to minimize the risk of stock collapse in data-limited fisheries.

In light of the YPR analysis conducted in this report, many species may be growth over fished, that is to say that too many of the young fish are being caught prior to their maturation. Furthermore analysis of the catch curves for some species indicates a total absence of smaller individuals in the catch, this may be due to their size class not being present on the fishing grounds or that the smaller cohort is already overfished and not present in the ecosystem. Nevertheless the results provide a serious indication that multiple stocks are overfished, and according to the YPR analysis, potentially underutilized.

It is important to clarify multiple assumptions that are part of the yield-per-recruit analysis. The YPR analysis assumes that the population is at equilibrium and the results are valid if natural and fishing mortality rated, along with those of age of entry into the fishery are representative of long term solution. If the age of entry into the fishery changes from year to year, or declines over time we may see a wholly different result. Furthermore, the estimates of natural mortality taken from the literature and estimated from the data (2007-2009) may not be representative of the long term situation. It is likely that the age structure of the populations in the Kaledupa fishery are not currently in equilibrium and that population may not remain the same in the future. This is import and to note because catch curve analysis used to estimate the current fishing mortality assumes that the age composition of the sample is representative of the entire population. this is dependent on all age classes being equally vulnerable to the gear used to collect the sample. This assumption is demonstrably violated in the gillnet fisheries, due to size selectivity of the different mesh size. This effect was corrected for in the YPR analysis by incorporating an age (length) based selectivity pattern the results should be taken as a potential relative guide.

Nevertheless the shape of the YPR curves, and the relative effects of the different mesh sizes (which determine the age /length of entry into the fishery) clearly show that the species are being underutilized due to their early selection in the fishery. By the YPR over fishing mortality and age of entry into the fishery (Figure 9) we see that the optimal age of entry for one species (Bluefin Trevally) is between 3 and 4 years old. In Kaledupa this species enters the fishery in the first year of its life.

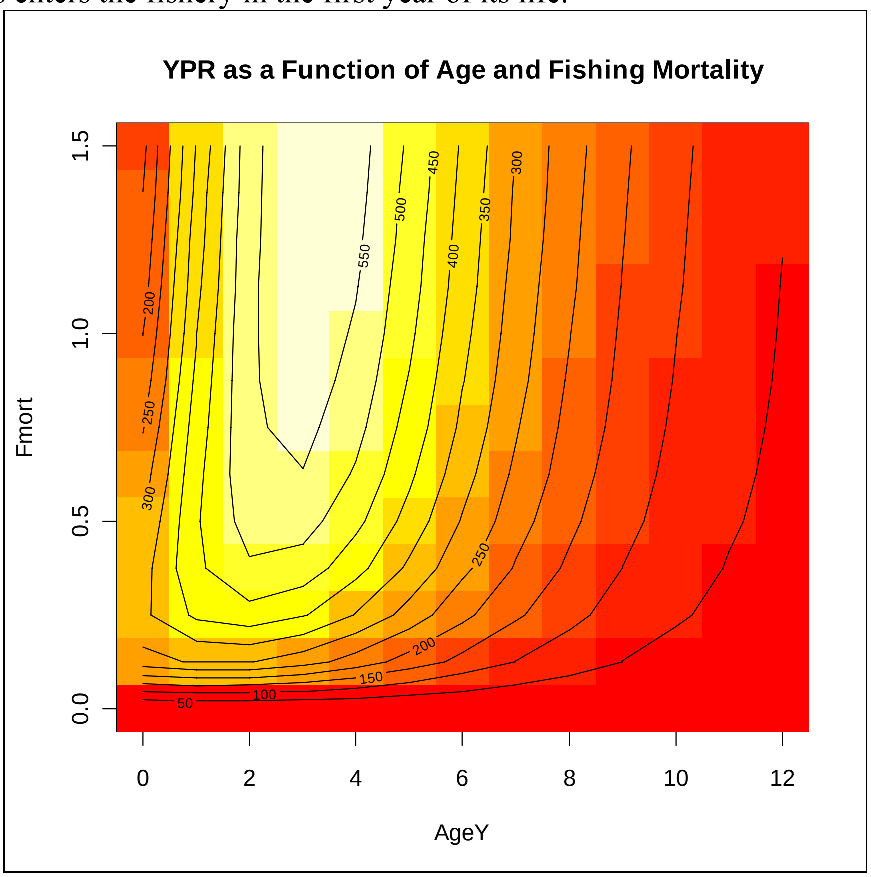

Figure 9. YPR as a function of age and fishing mortality for Bluefin Trevally.

Future Work

Specific projects on the following topics could greatly aid the management of the Kaledupa fisheries.

Reproduction and maturity data specifically the egg production data. Information on age and growth, and further documentation of life history parameters.

Seasonal analysis by specific location to assess the potential for seasonal closures or mesh size restrictions. Potential closures during spawning aggregations could greatly improve the life expectancy for many species.

An increase in monitoring activities.

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