# Comments on Myers & Worm (*Nature*, 423:280- 283, 15 May 2003)

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## 1   Introduction

Myers and Worm (2003) present an analysis of Japanese longline and trawl fishery catch and effort data for various ocean regions dating back to the beginning of industrial fisheries exploitation. Their analysis aggregates catch across species for each fishery type and interprets the aggregate CPUE so obtained as a time-series measure of "community biomass". Rapid declines in CPUE during the 1950s and 1960s were observed, leading the authors to suggest that "industrialized fisheries typically reduced community biomass by 80% during the first 15 years of exploitation", and that "large predatory fish biomass today is only about 10% of pre-industrial levels". In the case of tuna fisheries, in particular the fisheries for tropical tunas, these conclusions are fundamentally flawed. This note reviews the conclusions of Myers and Worm in relation to available data for the Pacific, concentrating on the region west of 150°W (referred to as the western and central Pacific). The comments are grouped under headings that deal with the main issues of concern with the Myers and Worm analysis.

## 2   Longline CPUE -  what does it measure?

Myers and Worm assume that longline catch per unit effort (CPUE) is proportional to or "indexes" the abundance of individual species, and further assume that simply adding together the catches, stratified by broad region and year, of  the different species and dividing by total effort provides an index of "community biomass". There are several problems with this approach. First, aggregating CPUE across species, which likely have very different population abundance and catchability by longline, is fundamentally flawed. For example, skipjack tuna probably has the highest abundance of tunas in the western and central Pacific (WCPO), but they have very low catchability by longline. Simply adding skipjack CPUE to, say, yellowfin CPUE, would not provide an index of the combined skipjack plus yellowfin abundance if the trends in abundance over time were different for the two species. This can be demonstrated mathematically as follows.

Let us assume that the abundance of a given species, s, is proportional to the CPUE of that species,

(1)
$$N_s = \frac{1}{q_s}\frac{C_s}{E}$$

where $C_s$ is the catch, $E$ is the effort, $q_s$ is the constant of proportionality (or catchability), and $N_s$ is the abundance. Then

$$(2) \qquad \sum_s N_s = \sum_s \frac{1}{q_s} \frac{C_s}{E}$$

Myers and Worm are assuming that the abundance of a "community" of species is proportional to the CPUE of the community, i.e.

$$(3) \qquad \sum_s N_s = \frac{1}{q'} \frac{\sum_s C_s}{E}$$

However, it is not algebraically possible to manipulate equation 2 to get equation 3 unless it is assumed that catchability is the same ($q'$) for all species. Therefore, the notion of "community biomass" as presented by Myers and Worm is not supported by an operational definition and is scientifically baseless.

A second major issue concerns the size or age selectivity of longline gear. Longlines do not randomly sample pelagic populations but tend to select mainly the largest and oldest members of the populations. Therefore, longline CPUE, at best, might index that portion of the population that is vulnerable to the gear, but not the whole population. Myers and Worm make little effort to point out this distinction in their paper, and give the clear impression that their results actually apply to the whole population biomass of the species making up their "communities". It is therefore not surprising that the popular media also miss this important point, with the message currently being given that 90% of pelagic fish everywhere have been removed by longline. A simple simulation demonstrates the point (Figure 1). Here, a single age-structured population is modelled from the beginning of exploitation over a period of 25 years with intense exploitation (fishing mortality of 3x natural mortality for the fully selected age-classes). The selectivity by age-class (right panel of Figure 1) is a typical tuna longline selectivity schedule. While longline CPUE declines rapidly under this exploitation to less than one-third of the initial level, the overall population declines to only 70% of the pre-exploitation biomass. Even if we accept that longline CPUE accurately indexes the longline exploitable population, it is incorrect to infer that the CPUE indexes the entire population, or even the entire adult population. The reduced population biomass in this simulated example is well above that providing the maximum sustainable yield, and would not be considered to be over-exploited by any commonly used fisheries management standards.
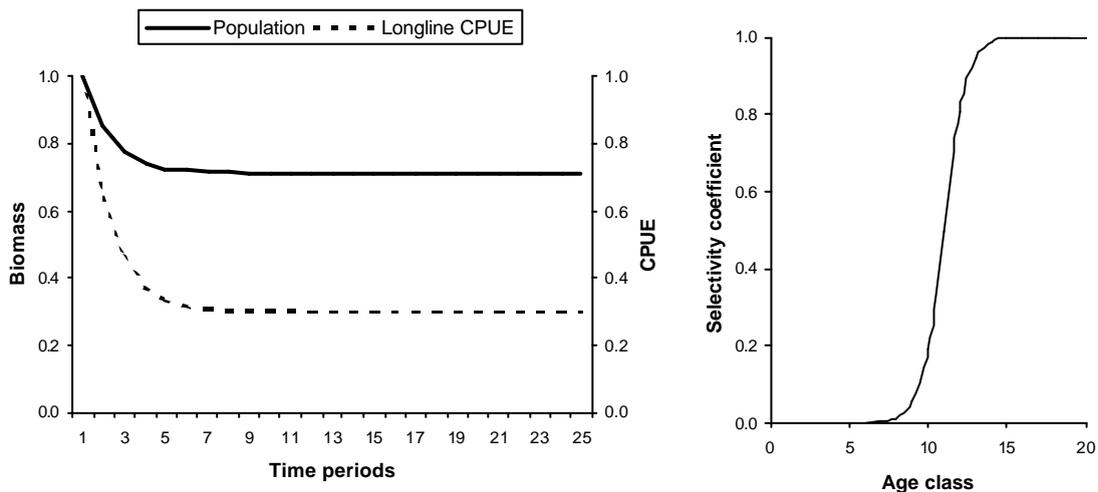


**Figure 1. Simulated longline CPUE and population abundance trends (left) resulting from age-specific exploitation (right) typical of longline gear. Natural mortality = 0.2, fishing mortality = 0.6 for fully selected age-classes.**

Myers and Worm attempt to respond to other criticisms of the reliability of longline CPUE as an index of abundance in the supplementary information available from the Nature web site. These may be summarised as follows:

**Inconsistency of CPUE declines with catch**

This is a key issue, because the CPUE declines mostly occurred during periods of relatively low total catch (and longline catch in most cases) for most of the species considered. The inference is that if these low catches caused stock-wide declines in population biomass, then the biomass must have been low to begin with. The problem is that such low initial populations are irreconcilable with subsequent large catches that were taken. The authors claim that the CPUE trends are in fact reconcilable in the case of southern bluefin tuna and Atlantic bluefin tuna. Stock assessment scientists familiar with those assessments may care to comment on that. However, for two tropical species (yellowfin and bigeye tuna) for which full age-structured assessments have been undertaken utilizing all available data back to 1952 (i.e. including the same data analysed by Myers and Worm), the models cannot attribute the change in longline CPUE to a fishery-induced decline in population abundance, even when the models are spatially stratified[1]. The declines in CPUE are attributed either or both of two things: (a) a decline in population abundance brought about by a decline in recruitment (or, put another way, the model attributes the high initial CPUE to abnormally high abundance brought about by abnormally high recruitment during the initial years of the model); and (b) unusually high effectiveness of fishing effort (or high catchability) during the initial years. These assessments will soon be presented to the annual Standing Committee on Tuna and Billfish (9-16 July, 2003 in Mooloolaba, Australia) and will subsequently be prepared for peer-reviewed publication. The major results for the yellowfin analysis that demonstrate the above points are shown in the Appendix.

Myers and Worm propose that the yellowfin case is most easily explained by an increase in juvenile survival (i.e. a decline in natural mortality) linked to a decline in predator abundance. This hypothesis is unlikely because if such enhanced survival had occurred as a result of declines in predator abundance in the 1950s, longline CPUE for species such as yellowfin should have risen sharply as these fish recruited to the longline exploitable population in the early 1960s. This increase in CPUE was not observed.

**Inconsistency of CPUE declines with changes in size composition**

If the CPUE declines of the magnitude observed were representative of stock-wide reductions in abundance, as claimed by Myers and Worm, we would expect the size composition of longline catches to have changed to some extent over the period in which the majority of the CPUE decline occurred (i.e. the first 15 years of exploitation). In the supplementary information, Myers and Worm suggest that this is only an issue with some billfish stocks, which in any case can be explained by "unusual growth patterns". This explanation is unclear and should be clarified. SPC is currently attempting to assemble all available size composition data for yellowfin, bigeye and albacore tuna for incorporation into assessment models. However, simple simulations show that even under extremely heavy levels of longline exploitation, the change in length frequency distribution of the catch is fairly subtle – in one yellowfin-tuna-like simulation, we obtained only a 8% reduction in average length with a 80% decline in CPUE, and the change was almost immediate, mostly within the first year. Such changes are unlikely to be detectable during the 1950s when sampling effort in the fishery was low.

**Changes in the depth distribution of longline gear**

Myers and Worm point out that the most significant changes in longline fishing strategy with respect to targeting occurred in the 1970s well after the main declines in CPUE had occurred. The targeting change referred to here was the deeper sets designed to better target the deeper swimming bigeye tuna. This however is not the whole story. In the 1950s and early 1960s, the Japanese longline fleet was targeting albacore tuna in the sub-equatorial areas of the Pacific Ocean. Later, yellowfin and

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[1] Spatially-stratified models should be better able to distinguish local effects (at the spatial resolution of the model) from stock-wide effects.

bigeye (in particular) were targeted. As shown later, these targeting changes are likely to have impacted species-specific CPUE.

**Shark damage on longline sets**

Myers and Worm claim that their results are conservative because the early CPUEs for tuna and billfish were depressed by higher levels of shark damage than in recent times. They cite two Japanese publications from the 1950s and 1960s and one SPC study from the 1990s in support of this claim. We are not familiar with the Japanese studies, but in the SPC data, the rates of shark damage per longline set are extremely variable, ranging from zero to >50% of tuna damaged. This suggests that taking simple average rates and comparing them without consideration of the spatial/seasonal distribution of the samples and without quoting confidence intervals may be extremely misleading. Also, more extensive Japanese data suggests that there has in fact been little change in rates of shark damage over the years (Z. Suzuki, pers. comm.).

# 3   Spatial Issues

The Myers and Worm study excludes all longline data in the Pacific north of 10ºS latitude. The entire north Pacific ocean and the core habitat of a dominant tropical species, yellowfin tuna, is excluded. The other dominant tropical species, skipjack is very poorly sampled by longline gear and therefore not reflected in the CPUE trends. Japanese tuna production in the Pacific reached its pre-WWII maximum in 1940 (116,000 and 86,000 tonnes of skipjack and "tuna" respectively), fell to very low levels during the war, and only surpassed pre-war levels in the early 1950s. Prior to the war, there were no large-scale longline fisheries. Japanese fishermen conducted some experimental longline operations in Indonesia, and most of the Japanese distant-water tuna catches came from pole-and-line operations at fishing bases in Micronesia. After the war, movements of Japanese fishing vessels were constrained by United States policies that were not removed until 1950. Furthermore US atomic testing in Micronesia limited the areas where fishing could be safely practiced[2]. Thus, the north Pacific tuna populations were very lightly fished prior to 1952 and should have been included in the analysis[3]. Excluding Pacific waters north of 10ºS restricts the analysis to the margins of the distributions of the most tropical species. Omission of the core habitat of two of the most abundant large predators, yellowfin and skipjack, could seriously bias the conclusion.

In Figure 2, the distributions of catch by year (1950–1961) for the main tuna species (and which dominate the CPUE trends presented by Myers and Worm for the Pacific) are presented. Several points are noteworthy:

1. In 1952–1954, fishing is very restricted in the "tropical" and "subtropical" areas, as defined by Myers and Worm, to a few 5-degree squares in the Coral Sea near the coast of Australia. In these years, catches are dominated by yellowfin, with highest catches occurring in the 1st and 4th quarters. In 1955, the fishery moved to the east, and albacore (then the main target species) dominated the catch. These relatively fine-scale spatial changes may well have impacted the early CPUE trends.

2. The majority of the yellowfin and bigeye catches occur in the equatorial zone, between 15°N and 10°S. This region was not considered part of the "tropical" area by Myers and Worm, but clearly it should have been if stock-wide inferences are to be made.

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[2] Matsuda, Y. and K. Ouchi. 1984. Legal, political, and economic constraints on Japanese strategies for distant-water tuna and skipjack fisheries in southeast Asian seas and the western central Pacific. Mem. Kagoshima Univ. Res. Center S. Pac., 5(2):151-232.

[3] We are currently compiling published data documenting Japanese fishing activity between the Equator and 10°N in the western Pacific in 1950 and 1951. These data are available in Murphy, G.I. and Otsu, T. 1954. Analysis of catches of nine Japanese tuna longline expeditions to the western Pacific. U.S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 128, 46 pp. This report is readily available and could have easily been incorporated into the Myers and Worm study.

3. Most of the catches in the temperate area are of other species, which in these years is almost exclusively southern bluefin tuna.
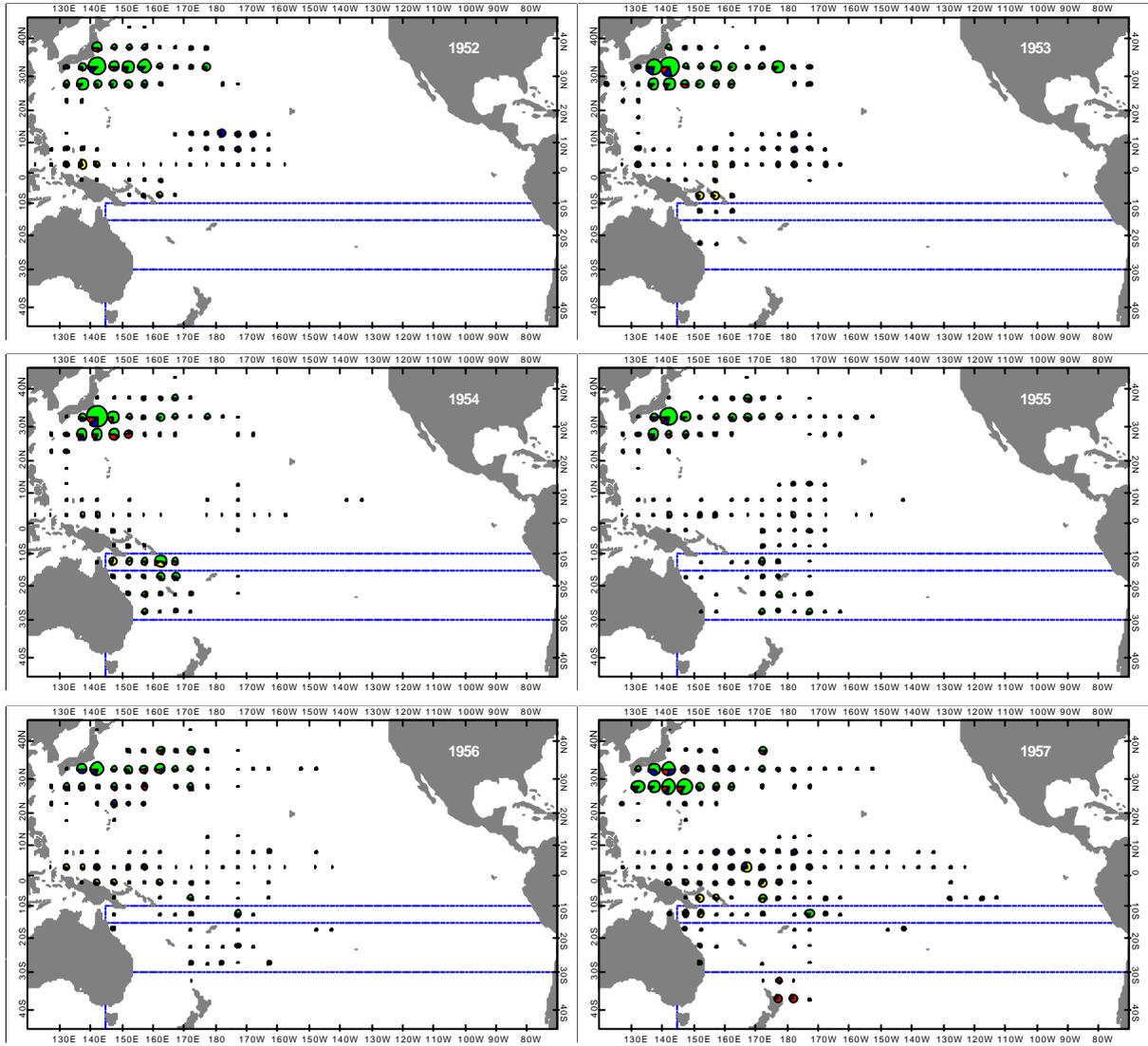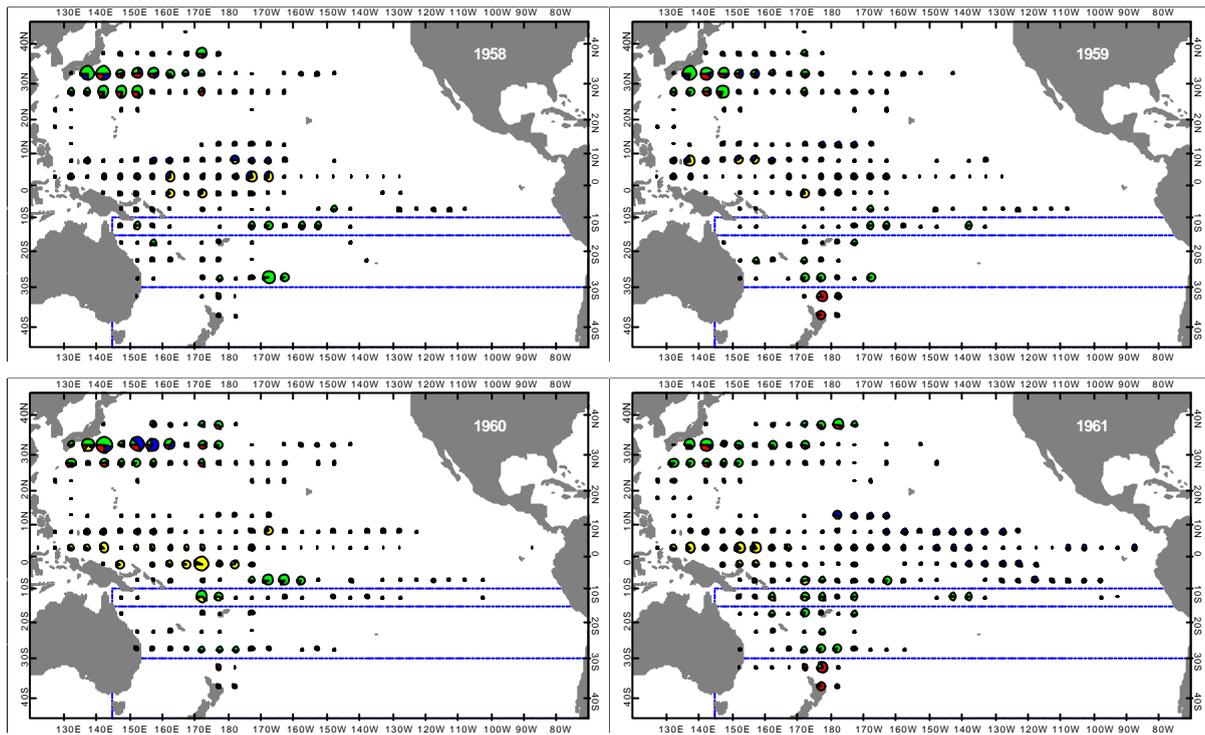
**Figure 2. Distribution of Japanese longline catches of albacore (green), bigeye (blue), yellowfin (yellow) and other species (red), 1952- 1961. The "tropical", "subtropical" and "temperate" areas as defined in Myers and Worm are shown.**

# 4 Species-Specific CPUE

As noted earlier, it is not valid to aggregate the CPUE of species with different catchability and abundance trends to obtain an index of "community biomass". The list of species included in the analysis comprises a range of life history patterns ranging from species that are short-lived and rapidly growing with widespread spawning grounds to species which are long-lived and slowly growing with restricted spawning grounds. In this section, species-specific CPUE trends are considered.

The trends for the tropical, subtropical and temperate regions, as presented by Myers and Worm, are re-created from SPC databases in Figure 3. We do not consider years in which fewer than 200,000 hooks (about 100 longline sets) were made. Myers and Worm had a more lenient data screening policy (20,000 hooks, or about 10 longline sets, which seems inadequate to cover such large spatial strata). The main reason for showing Figure 3 is to demonstrate that our database is essentially identical to that used by Myers and Worm in constructing their Figures 1g, h and i, and that the declining trend for the temperate area is completely dominated by southern bluefin tuna. When SBT is removed, there is no declining trend for the remaining species.

Species-specific CPUE trends for the tropical and subtropical areas are shown in Figure 4. For yellowfin, more than half of the overall decline in CPUE occurs between 1953 and 1954. Given the restricted distribution and relatively low fishing effort in these years, it is difficult to say if this CPUE decline is representative of an abundance decline throughout the entire respective areas. Given what we know about yellowfin mixing rates[4], this is highly unlikely. A general linear model has been fitted to these data for incorporation into stock assessment analyses. The fitted year effect has confidence intervals that are extremely high for the early 1950s, indicating that CPUE has low precision as an index of abundance during this period (Figure 5).

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[4] Sibert, J. and Hampton, J. 2003. Mobility of tropical tunas and the implications for fisheries management. *Marine Policy* 27: 87–95.

It is noteworthy that increases in albacore CPUE occurred at the same time as the declines in yellowfin CPUE. This is likely to have resulted from the spatial movement of the fleet (Figure 2) and more consistent targeting of albacore for the canned tuna market. Albacore CPUE peaked in the early 1960s and then declined, which is also likely to be related to a change in targeting behaviour towards bigeye, and to a lesser extent, yellowfin. Note that bigeye CPUE gradually increased throughout the pre-1980 period in both areas.

Attributing the rapid decline in albacore CPUE in the 1960s to a change in targeting behaviour is supported by the pattern of albacore CPUE by the Taiwanese fleet. The Taiwanese fleet began its operations in the mid-1960s, and has consistently targeted albacore in these regions since that time. The initial albacore CPUE by this fleet in the late 1960s was much higher than the Japanese CPUE at the same time, and was comparable to the early 1960s Japanese CPUE when they were targeting albacore. The Taiwanese CPUE declines gradually over time, as would be expected as effort increased and other national fleets entered the fishery.

It is clear that the CPUE trends are quite different for the different species in the regions considered. Myers and Worm need to explain how these different trends could have occurred, given the very general nature of their claims about the impact of early longline fishing.
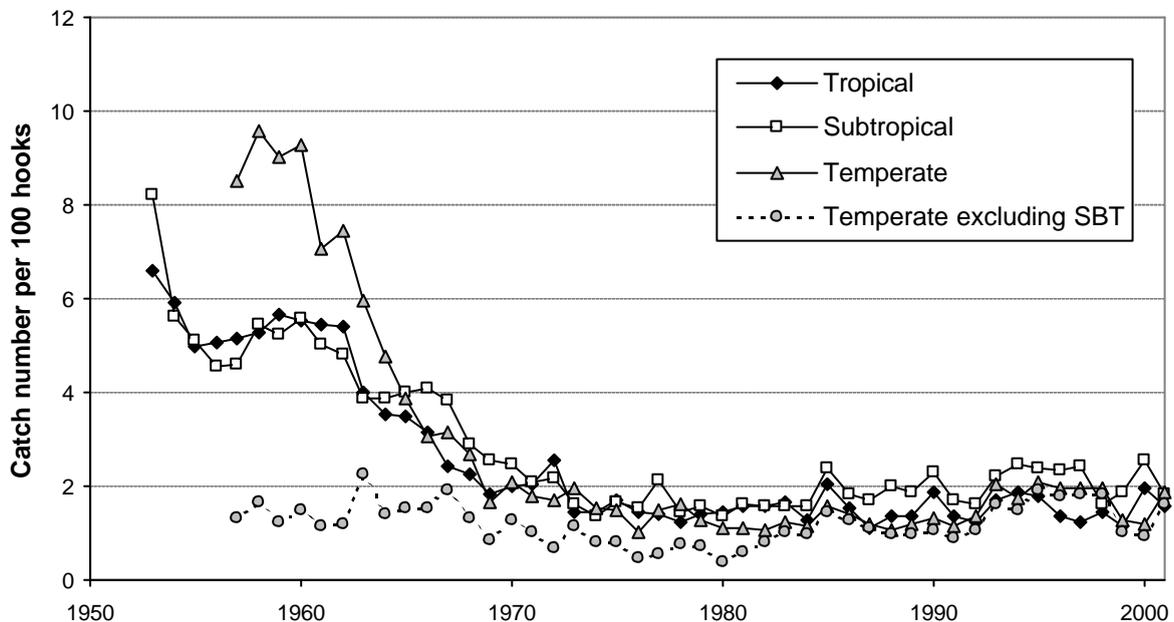


**Figure 3. Composite trends in CPUE for all tuna and billfish reported in Japanese longline statistics for the tropical, subtropical and temperate areas as defined by Myers and Worm.**

As noted earlier, we believe that Myers and Worm should have considered a larger tropical area in their analysis, incorporating the major core habitat of the main tropical tunas captured by longline, i.e. yellowfin and bigeye. CPUE trends for these species for an extended tropical area are shown in Figure 6. Declines in CPUE occur for both species, but they are neither rapid nor spectacular. Various analyses suggest that the decline in yellowfin CPUE probably exaggerates the decline in abundance due to Japanese longliners progressively switching to deep-setting gear from the mid-1970s. For the same reason, the decline in bigeye CPUE probably underestimates the decline in abundance to some extent.
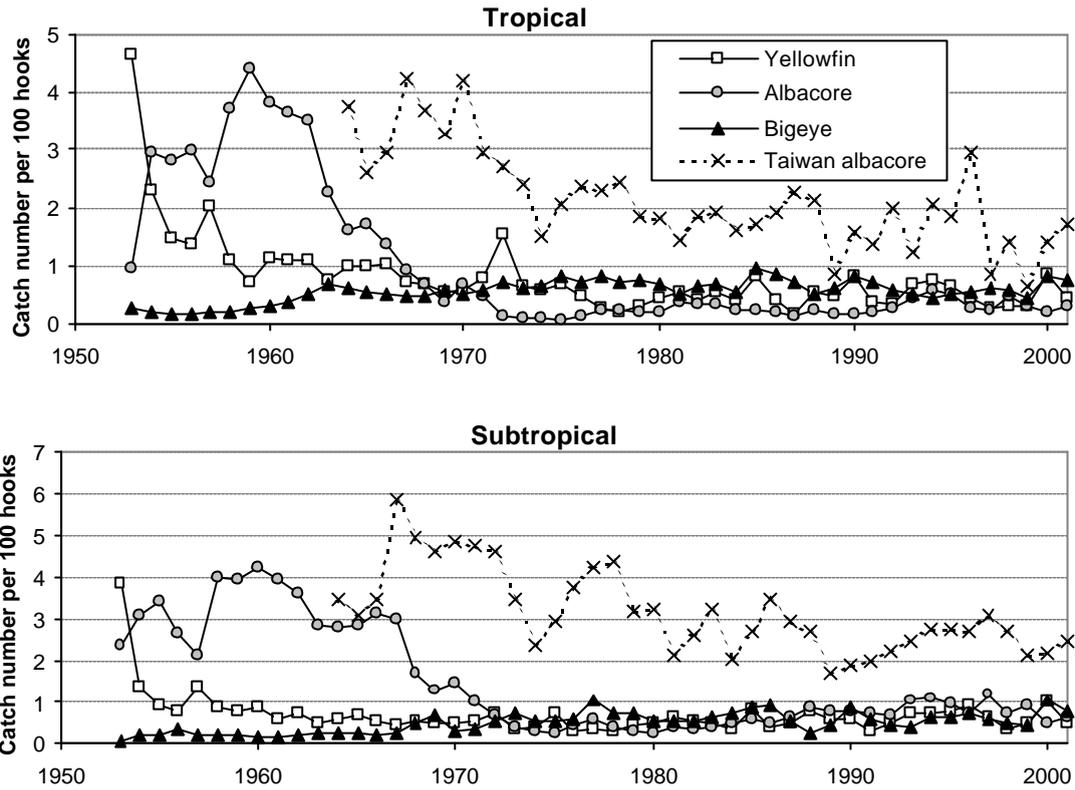
**Figure 4. Species-specific CPUE for the tropical and subtropical areas as defined by Myers and Worm.**
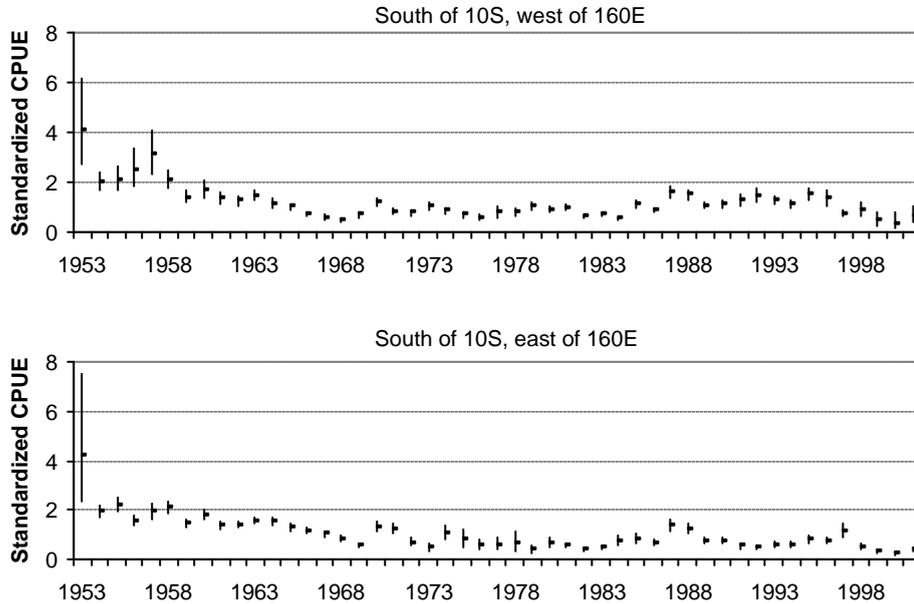


**Figure 5. Standardized CPUE with 95% confidence intervals obtained from a general linear model analysis of yellowfin tuna data for the western and central Pacific south of 10°S.**
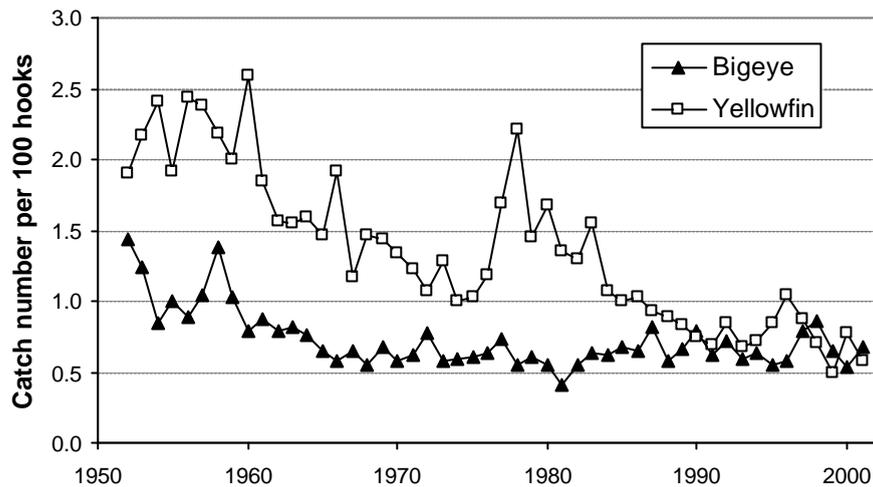
**Figure 6. Japanese longline CPUE for yellowfin and bigeye tuna in the western and central Pacific Ocean, 15°N- 10°S, 120°E- 150°W.**

# 5   Modelling

The model fit to the CPUE time series in Myers and Worm is a simple exponential decay to a constant level. In the supplementary material the authors dismiss the use of logistic population models as being overly simplistic, but their model is very similar to a logistic model that starts displaced far above its equilibrium level. The population dynamics are reduced to three parameters in both cases, and neither can adequately reflect dynamics of populations exploited by multiple gears with various catchabilities and selectivity-at-age schedules. The model adopted by Myers and Worm is particularly inappropriate because it does not recognize any limits to unexploited population size or carrying capacity, and the functional form of the model in fact forces high estimates of initial relative abundance. The authors do not consider age and spatially structured population dynamic models that would be capable of capturing the dynamics of populations subject to such complexities. As seen in the appendix, our models not only show that the catches obtained during the early years of the fishery are not consistent with the declines in the CPUE and later fishery production, but also provide an explanation for steep declines in CPUE that is consistent with realistic population dynamics. Summation across species exacerbates the omission of population dynamics as well as the fundamentally flawed assumption that CPUE is an index of global abundance.

# 6   Summary

- The Myers and Worm study is fundamentally flawed because of the aggregation of CPUEs for different species that show different time-series trends and have different longline catchability and uncritical interpretation of pooled CPUE as an index of "community biomass".

- The popular interpretation of the results of the study as indicating population or community level changes in abundance is incorrect. Longline gear selects mainly the oldest fish and therefore the conclusions of the study should be more restricted.

- The Myers and Worm definition of tropical area for the Pacific is too restrictive and should have included the main core habitat of tropical tunas and billfish (to 15°N). Their claim that this area could not be considered because it was fished prior to 1952 is grossly overstated. Available information suggests that longline fishing effort prior to 1952 in the equatorial area was very low and largely of an exploratory nature. Declines in CPUE of yellowfin and bigeye in this region are neither rapid nor spectacular.

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- The declines in CPUE documented in the Myers and Worm study show considerable differences among species in the western and central Pacific. Most of the visual impact of the decline occurs because of a very high yellowfin CPUE in 1953, when fishing was very spatially restricted and occurred in only part of the year. Changes in albacore CPUE are demonstrably related to species targeting when data from other fleets (Taiwan) are considered. No decline in bigeye CPUE occurred in any region considered over the entire time series. Decline in CPUE in the temperate region is restricted to southern bluefin tuna. The onus is on Myers and Worm to explain how these very different patterns could have resulted given the general claims that they make regarding the impact of longline fishing on pelagic fish stocks.

- The species-specific changes in CPUE need to be assessed in the context of models that incorporate species-specific population dynamics and make use of a greater range of data than catch and effort statistics from one fleet using one gear. Size-based age-structured models are currently being used for the main species exploited by longline in the western and central Pacific. The results of these analyses will be available within two months.

- There is no doubt that fishing decreases the abundance of fish populations. The simplest of fishing theories predict that the size of fish populations at full and sustainable exploitation is about half of their pre-exploitation size. Many of the tunas and billfishes included in this analysis have been carefully assessed by sophisticated models that include multiple gear types, spatial effects, age structure, and long time series. Most of these analyses estimate declines that are far less severe than indicated by the nominal CPUE. There is also no doubt that some fish populations are overexploited, that others are near full exploitation, and the steps need to be taken to reduce levels of exploitation. Myers and Worm do the fisheries community a disservice by applying a simplistic analysis to the available data which exaggerates declines in abundance and implies unrealistic rebuilding benchmarks.

## Appendix: Preliminary results from the 2003 western and central Pacific yellowfin tuna assessment

The yellowfin tuna assessment utilizes modern stock assessment methodology known as MULTIFAN-CL[A1]. Complete catch and effort data for all significant fishing gears, as well as size composition and tag-release-recapture data are incorporated into the model. The model is spatially stratified into five regions (Figure A1), and has a temporal structure of year quarter, beginning in 1952. The model is age-structured and comprises 28 quarterly age-classes. Fishing mortality for each of 17 distinct fleets is modelled as a combination of separable age-specific (selectivity) and time-specific (effort, catchability and effort deviations) effects. Natural mortality rates, which are estimated, are assumed to be age-specific, but constant over time. Recruitment is also estimated and occurs independently in each region at each model time step, with some constraining assumptions concerning the spatial and temporal variability. Full details of an earlier version of the model can be found at http://www.spc.int/OceanFish/Html/SCTB/SCTB15/YFT-1.pdf.
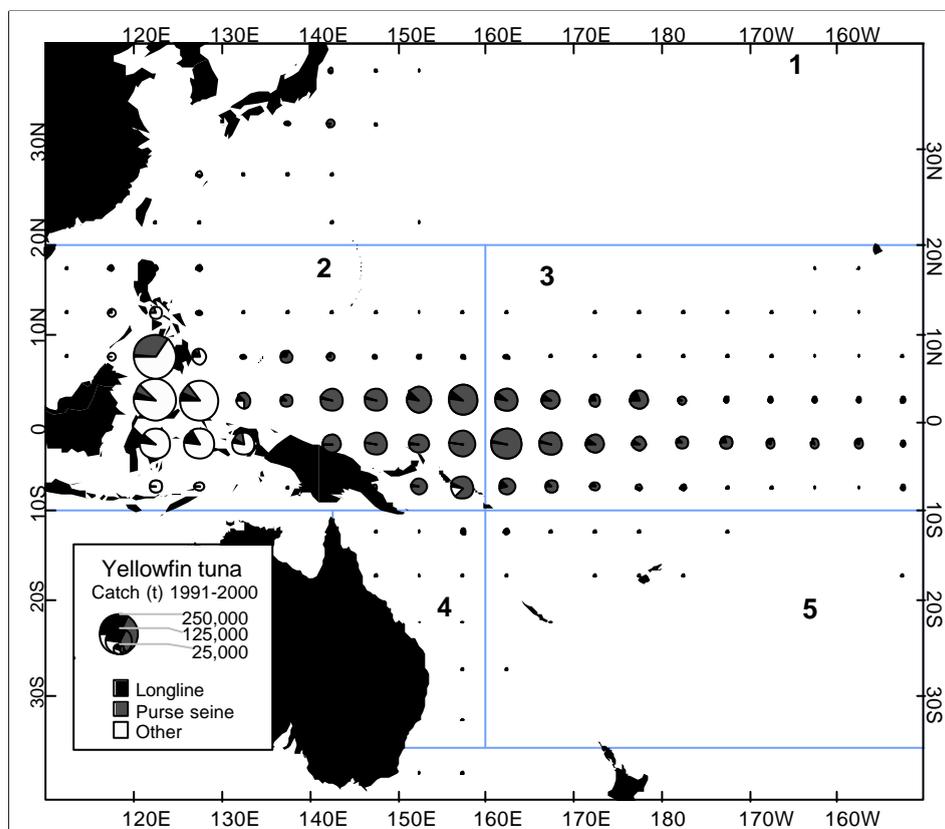


**Figure A1. Spatial stratification used for the yellowfin tuna assessment model.**

Regions 4 and 5 of our model correspond approximately to the combined tropical and subtropical regions of the Myers and Worm analysis, and the CPUE data for our regions show the same pattern of high initial longline CPUE followed by a steep decline. Estimates of total population biomass by region are shown in Figure A2. Whole population biomass declines significantly over time, to around half of the early 1950s level. However, overall declines during the 1950s and 1960s, during which time Myers and Worm claim that 80% of the biomass was removed, are relatively modest. There is a

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[A1] Hampton, J., and Fournier, D.A. 2001. A spatially disaggregated, length-based, age-structured population model of yellowfin tuna (*Thunnus albacares*) in the western and central Pacific Ocean. *Marine and Freshwater Research* **52**: 937–963.

rapid decline in biomass in one of the regions (5), which corresponds to part of Myers and Worm's tropical area. However, our model attributed this decline to above average recruitment in region 5 during the initial time periods (Figure A3), rather than depletion due to fishing. Our results are therefore consistent with the CPUE data, and provide a plausible explanation of the early decline in one part of the stock distribution. Our results are also consistent with other data in the assessment (including the large purse seine catches that began in the mid-1980s) and with yellowfin tuna population dynamics, unlike the hypothesis of an 80% stock-wide decline in biomass attributable to longline fishing proposed by Myers and Worm.
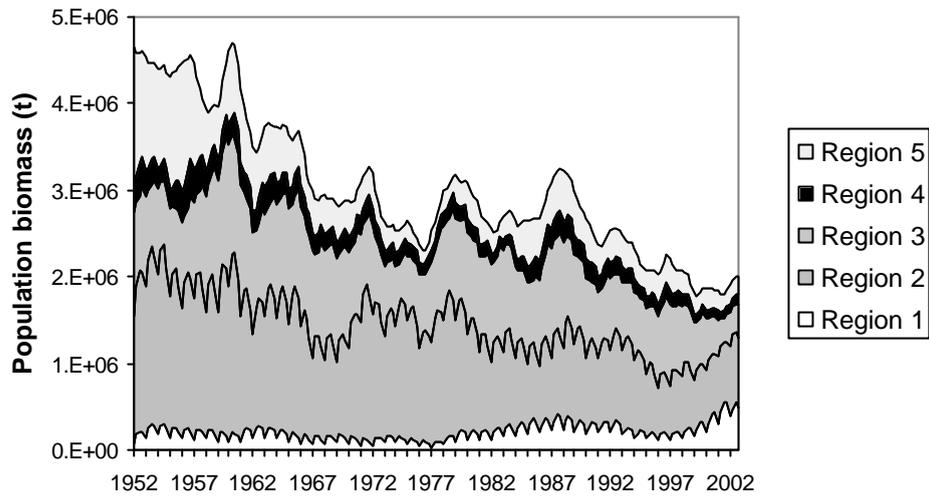


**Figure A2. Estimates of yellowfin tuna population biomass, stratified by model region (see Figure A1).**
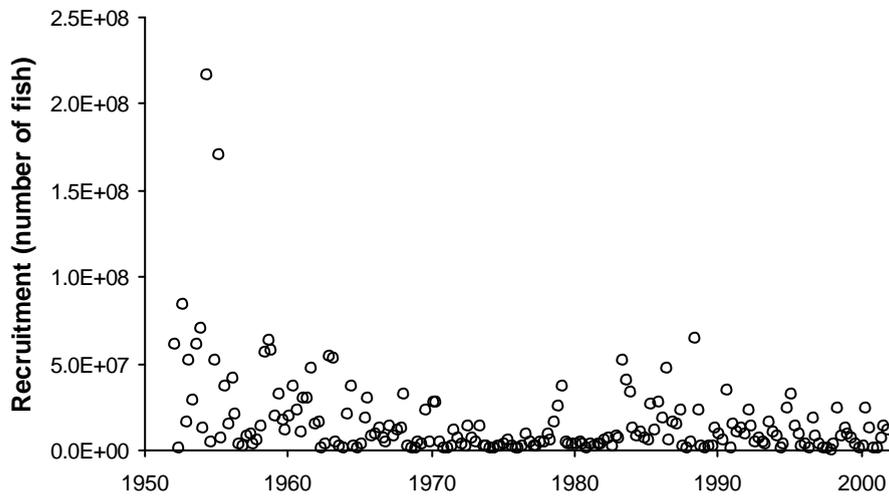


**Figure A3. Estimated quarterly recruitment of yellowfin tuna in region 5.**