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SPATIAL AND TEMPORATL VARIATION IN THE SIZE COMPOSITION OF THE YELLOW FIN AND BIGEYE LONGLINE CATCH IN THE WCPO

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1. Introduction

Size frequency data (length and weight) represents an important input into the yellowfin and bigeye stock assessments for the Western Central Pacific Ocean (WCPO) (Hampton et al 2005a, 2005b). The assessment models are spatially structured into regions (Figure 1). The regional structure of the MFCL assessments implies a homogeneous size structure within each region of the model. This assumption has not been examined for yellowfin and bigeye and represents an important component of the review of the current (2005) region boundaries (see Langley 2006a).

The Japanese distant-water longline fleet has provided the most comprehensive set of length and weight samples from the yellowfin and bigeye catches in the WCPO. This paper presents an analysis of the temporal and spatial trends in fish size (weight and length) from the sampled catch. The analysis, in conjunction with an analysis of the associated trends in catch and effort data, enables a review of the current region boundaries. In addition, the paper provides an opportunity to examine long-term trends in fish size in the WCPO that may provide further insights into spatial differences in exploitation rates and recruitment.

2. Methods

Size frequency data (length and weight) from the Japanese distant-water longline fleet operating in the WCPO were available from 1948–2004. These data were aggregated by year/quarter and spatially at a number of different levels of resolution: 10 degrees of latitude and 20 degrees of longitude, 10 degrees of latitude and 10 degrees of longitude, and 4 degrees of latitude and 8 degrees of longitude.

The size data were reaggregated to the broadest level of resolution available for the entire time period, i.e. 10 degrees of latitude and 20 degrees of longitude. Each block was defined by the location of the southwestern corner, for example, the block denoted “00N 140E” encompasses the area from the equator to 10ºN and from 140ºE to 160ºE (for example, Figure 2).

For each block included within a specific MFCL region, the annual median fish size (weight or length) sampled was calculated. Fish weights were expressed as whole weights following the application of a conversion factor to processed fish weights following Langley et al. (2006). Trends in fish size were compared between the main blocks that encompass a MFCL model region.

The number of samples from each block was also examined to investigate the influence of sample distribution on the aggregated regional size composition. These analyses were conducted for each of the main yellowfin and bigeye longline fisheries; regions 3–5 for yellowfin and regions 2–5 for bigeye (Table 1).

For each species, decadal trends in fish size through the main fishery areas of the WCPO were also examined.

3. Results

3.1. Yellowfin

3.1.1 Region 3

For the Japanese distant-water longline fishery in region 3, the size of fish sampled for length and weight declined from the 1950s to the mid 1970s (Figure 3). This was followed by an increase in fish size through the 1980s and a steady decline from the early 1990s to recent. There was some deviation in the recent trends between the two sources of data with a greater decline in fish size evident from the length data. In recent years, at a regional scale, fish sizes in the weight samples have been consistently larger than for the corresponding length samples (Figure 3).

An examination of the trends in size composition of the six main sub-regional blocks that comprise region 3 (Figure 2) revealed the following observations.

- Trends in median weight are comparable for three of the sub-regions ("00N 120E", "00N 140E", "10N 140E") (Figure 4). These sub-regions account for a high proportion of the weight samples.
- Median fish weights from "10S 140E" — approximately the waters of PNG — were smaller than for other sub-regions, particular prior to 1980 (Figure 4).
- Median sampled fish weights from "10N 120E", the waters of the South China Sea and Philippine Sea, were similar to the other main sub-regions prior to the mid 1980s but were dominated by much smaller fish in the subsequent years (Figure 4).
- Overall, the decline in fish sample weights in the 1970s (Figure 3) is partly attributable to a higher proportion of weight samples from "10S 140E" — the sub-region dominated by smaller fish. However, all sub-regions revealed a decline in sample weight in the mid–late 1970s. Sample weights in most regions increased in the late 1980s, with the exception of "10N 120E". The increase in the proportion of samples from this area since 1990 (Figure 4) is partly responsible for the strong decline in the overall median weight for the entire region (Figure 3).
- Most of the yellowfin length samples from region 3 were collected prior to 1980 (Figure 5). Fish in the northern sub-regions ("10N 120E", "10N 140E") were substantially larger than from PNG waters ("10S 140E"), while fish from the vicinity of FSM waters ("00N 140E") — the other main sub-region sampled — were of intermediate size (Figure 5).
- The overall decline in the median length of sampled fish from region 3 (Figure 3) in the 1960s and 1970s is partly attributable to an increase in the proportion of the length samples obtained from the PNG sub-region ("10S 140E") (Figure 5).
- Limited length data are available from 1980 onwards (Figure 5) and the size sample is dominated by smaller fish from "10N 140E". These samples are driving the overall decline in fish length observed for the region (Figure 3).
- Compared to the distribution of longline catch from region 3 (Figure 6), the distribution of sampled fish weights from "10N 120E" and, to a lesser extent, "10N 140E" is over-represented in the cumulative weight sample from the last decade. While, length samples from "00N 140E" are over-represented in the cumulative length sample in the early 1970s.

3.1.2 Region 4

For the Japanese distant-water longline fishery in region 4, the size of yellowfin sampled for both length and weight declined steadily from the mid 1950s to 1980 and remained relatively stable for the remainder of the period (Figure 7).

Trends in the median sampled fish weights and lengths from the six sub-regions comprising region 4 revealed the following trends.

- There are differences in the median weight of fish between the sub-regions with fish in the western equatorial sub-regions ("10S 180W", "00N 180W") generally smaller than fish sampled further east ("10S 160W", "00N 160W", "10N 160W") and in the northwest ("10N 180W") (Figure 8). Annual trends in the median weight within these sectors of region 4 were similar (Figure 8).
- The sub-regional length data also indicates that slightly smaller fish are caught in the two western equatorial sub-regions ("10S 180W", "00N 180W") (Figure 9).
- The overall trend in median fish length (Figure 7) is broadly consistent with the trends in fish length for each of the sub-regions comprising region 4 (Figure 9).
- Compared to the distribution of longline catch from region 4 (Figure 10), the distribution of sample weights from "10N 180W" is over-represented in the cumulative weight samples from the early period of the fishery through until the 1980s. Length samples from "10N 180W" are also over-represented in the cumulative length samples in recent years.

3.1.3 Region 5

For the Japanese distant-water longline fishery in region 5, both the length and weight samples reveal a strong initial decline, although the trends diverge somewhat over the remainder of the study period (Figure 11). The median length steadily increases from the early 1980s and recent year's samples are dominated by large fish. In contrast, the median weight is variable between 1970 and 2000 but reveals no strong trend in size (Figure 11).

In general, yellowfin sampled for weight in the northern sub-region of region 5 ("20S 140E") — the Coral Sea — were smaller than fish sampled from the two southern sub-regions ("30S 140E", "40S 140E") (Figure 12). The decline in the proportion of total weight samples collected from "20S 140E" in the late 1960s and early 1970s (Figure 12) accounts for the increase in overall median weight during this period (Figure 11). For the remainder of the period, the distribution of sampling effort between the three sub-regions was highly variable and, consequently, the overall median weight also varied considerably. For example, the increase in samples from "20S 140E" in the mid 1980s resulted in a reduction in the overall aggregated median weight during this period (Figure 11).

The length samples also reveal yellowfin in the Coral Sea ("20S 140E") are considerably smaller than fish sampled from the two southern sub-regions (Figure 13). Over the initial sampling period there was a steady increase in the proportion of the length samples collected from the northern Coral Sea sub-region (Figure 13). This partly explains the strong decline in the overall fish length sampled in the 1950s and 1960s (Figure 11). However, declines in fish length were also apparent in the two main sub-regions sampled ("20S 140E", "30S 140E") and the spatial shift in sampling effort may have just exaggerated this decline in the combined data set.

The distribution of weight samples between 10*20 latitude/longitude sub-regions is broadly comparable with the distribution of the longline catch between sub-regions (Figure 14). However, sampling for length was strongly biased to the Coral Sea sub-region ("20S 140E").

3.1.4 Decadal trends in fish size

The spatial trend in yellowfin size was investigated by calculating the median fish size (length and weight) for each 10 degree latitude and 20 degree longitude block by decade from 1950 to 2000.

These data reveal longline catches in the southwestern equatorial region (PNG waters) have consistently been comprised of smaller fish (Figure 15). During the 1950s–1960s, there was a strong spatial trend in the size of fish caught, with fish increasing in size eastwards and north and south from PNG waters. During the 1970s and 1980s, there was a general expansion of the area dominated by catches of smaller fish, particularly eastwards along the equator and into the South China Sea and Philippines Sea, with a corresponding reduction in the area dominated by larger fish. This trend persisted through the 1990s, although the lower level of sampling reduced the spatial extent of the data.

3.2. Bigeye

For bigeye tuna, temporal trends in the size (length and weight) composition were examined for the four main MFCL regions in the WCPO that account for a significant component of the total bigeye catch (regions 2–5).

3.2.1 Region 2

For the longline fishery in region 2, there was a strong declining trend in both median length and median weight from the 1950s to the mid 1980s (Figure 16). There was a slight increase in median fish size during the late 1980s and early 1990s followed by a decline over the last decade.

An examination of the trends in median fish weight between the sub-regions of region 2 reveals no strong difference in median fish weight between areas and all sub-regions exhibit temporal trends in fish weight consistent with the overall region (Figure 17). Trends in median length are also similar between sub-regions and broadly consistent with the weight sample data, with the exception of the strong decline in fish length observed in the late 1950s (Figure 18).

The increase in fish size in the early 1990s (Figure 16) appears to be driven by increased fish size within the northeastern area of the region (“30N 160W”, “30N 180W”). This trend is particular evident in the weight frequency data (Figure 17).

3.2.2 Region 3

The cumulative bigeye size composition (length and weight) data from the Japanese distant-water longline catch in region 3 (fishery 4) reveals a general decline from the late 1960s to the early 1980s (Figure 19). For the subsequent period, there is considerable divergence in the trends between the length and weight samples. Median length continued to decline steadily throughout the period, while median weight remained relatively stable until the mid 1990s and then declined rapidly over the last decade (Figure 19).

The weight sample data reveals differences in the size of fish between the 10*20 latitude/longitude sub-regions of region 3, with consistently smaller fish sampled from the PNG waters (“10S 140E”) and the South China Sea/Philippines Sea (“10N 120E”) compared to the northern equatorial regions (Palau, “00N 120E”; FSM, “00N 140E”) (Figure 20). Fish sampled from the area north of FSM waters (“10N 140E”) were intermediate in size.

The size of fish in the northern equatorial regions (“00N 120E” and “00N 140E”) remained relatively constant throughout the study period. In contrast, since 1990 there was a strong decline in median weight of fish sampled from the area north of FSM waters (“10N 140E”) and South China Sea/Philippines Sea (“10N 120E”) (Figure 20).

A relatively small number of fish were sampled for length from the region 3 longline fishery and sampling was principally conducted prior to 1980 (Figure 21). The length data reveal differences in fish size between sub-regions that are consistent with the weight sampling data; i.e. smaller fish in PNG waters ("10S 140E"), the area north of FSM waters ("10N 140E") and South China Sea/Philippines Sea ("10N 120E"). The recent decline in the overall median length (see Figure 19) is likely to be due to the dominance of samples from the area north of FSM waters ("10N 140E") (Figure 21).

Since the 1980s, weight samples from the two northern sub-regions ("10N 120E", "10N 140E") have represented a disproportionately high component of the total sampled catch relative to the distribution of total catch (see Figure 19). Given, the difference in size composition of catch from these two sub-regions, the distribution of sampling effort is likely to be biasing the overall sampled weight towards smaller fish.

3.2.3 Region 4

For the longline fishery in Region 4, there was a steady decline in fish size (length and weight) from the 1950s to mid 1980s (Figure 23). This was followed by a slight increase in size in the 1980s and then a further decline in size since 1990.

For each of the 10 degree latitude, 20 degree longitude blocks, trends in median fish weight were consistent with the overall trend for the region (Figure 24).

Most of the length samples were collected from two 10 degree latitude, 20 degree longitude blocks east of the dateline and north of the equator ("00N 180W", "10N 180W") (Figure 25). The trends in median length are broadly consistent between all blocks sampled (Figure 25) and comparable to the trend in the cumulative data set (Figure 23).

Since 1980, there has been a steady shift in the distribution of Japanese bigeye catch to the west of the dateline ("00N 160E") and in recent years a high proportion of the catch has been taken from this area of region 4; i.e. the northern equatorial region between 170°E and 180°. Limited sampling for length and weight from the sub-region has been included in the current analysis. This may be partly due to the spatial resolution of the size data with the respective 10 degree latitude, 20 degree longitude block dissected by the longitude boundary between MFCL regions 3 and 4 (170ºE). Consequently, these data were excluded from the analysis.

3.2.4 Region 5

Sampled lengths and weights of bigeye from the longline fishery in region 5 were highly variable between quarters and the two data sets do not reveal a consistent trend in fish size over the study period (Figure 27). Median weights were, on average, relatively stable between 1960 and 1980, declined during the early 1980s, and then remained relatively stable, at the smaller size, during the late 1980s and 1990s (Figure 27). There was a strong initial decline in the size of fish sampled for length and median fish length remained relatively constant, on average, until 1980. Length samples from the 1990s were comprised of larger fish (Figure 27).

Weigh data from individual 10 degree latitude, 20 degree longitude blocks reveals that fish in the Coral Sea ("20S 140E") are consistently small than for the more southern areas of the region (Figure 28). The median weight sampled from all blocks declined during the early 1980s. However, during the 1980s, an increased proportion of weight samples were taken from the Coral Sea area (Figure 28) and this may exaggerate the decline observed in the cumulative weight composition from the region (Figure 27).

Overall, limited length samples were collected from the region and most samples were collected from the Coral Sea area (“20S 140E”), particularly in the 1960s and 1970s (Figure 29). The increase in median fish length during the 1990s (see Figure 27) is likely to be attributable to a shift in the distribution of sampling to the more southern areas.

The differences in the spatial distribution of sampling for length and weight are likely to explain the inconsistencies in the trends in the cumulative median size data (Figure 27). Prior to 1980, weight samples were dominated by fish sampled from the more southern areas and, hence, were comprised of larger fish, while length samples from the same period were dominated by smaller fish sampled from the northern area (Figure 28 and Figure 29).

The spatial distribution of longline catch within region 5 is presented in Figure 30. In general, the distribution of catch is consistent with the weight sampling data, with the Coral Sea area (“20S 140E”) accounting for a significant component of the catch prior to 1960, an expansion of the fishery into the southern areas (“30S 140E”, “40S 140E”) in the late 1960s and 1970s, and a return to the Coral Sea area during the 1980s.

3.2.5 Decadal trends in fish size

There are some broad spatiotemporal trends in the size composition of bigeye in the WCPO from 1950 to 2000. The size composition data reveal an area of consistently smaller fish in the southwestern equatorial region, including the waters of PNG (Figure 31). During the early period of the fishery (1950s and 1960s) there was a steady increase in fish size to northward and southward from this area. However, the size of fish in the higher latitudes of the western WCPO declined through the 1980s and 1990s (Figure 31).

In the 1950s and 1960s, the fishery in the eastern areas of the WCPO was comprised of large fish (Figure 31). The area of larger fish contracted over the following three decades and the catches from the area east of the dateline became increasing dominated by smaller bigeye.

4. Discussion

The main purpose of this analysis was to identify the extent of variation in the size composition of the longline catch sampled from within each of the main regions defined in the current (2005) stock assessment for yellowfin and bigeye. The presence of significant within-region variation in size composition — either in terms of a consistent difference in fish size or a difference in the trend in fish size over time — would provide a justification for redefining the boundaries of the current (2005) regions. This review was undertaken in concert with an examination of the within-region trends in CPUE from the Japanese longline fishery (Langley 2006b).

The analysis of size data revealed that considerable spatial heterogeneity exists in a number of the main regions (regions 3 and 5), while the size composition was relatively homogeneous throughout other regions (regions 2 and 4). For both yellowfin and bigeye, there was considerable spatial structure in the size data from the western equatorial region (region 3), with smaller fish sampled from the northern waters of the PNG EEZ (including the Bismarck Sea) and a trend in fish size northwards (increasing for yellowfin and smaller bigeye in the more northern area). Within the same region, both species exhibited a very sharp decline in fish size in the area encompassing the South China Sea and Philippines Sea from the early–mid 1980s.

These observations from region 3 support the proposal for the redefinition of this region (Langley 2006a); the longitudinal subdivision of the region (at 135°E) is appropriate given the different trends in fish size since the early–mid 1980s, while altering the northern extent of the eastern section of region 3 (from 20°N to 10°N) is consistent with the observed latitudinal variation in fish size.

For region 5, both yellowfin and bigeye reveal an increase in fish size with increasing (southern) latitude. There is also some latitudinal variation in the CPUE trends from the region, particularly for bigeye (Langley 2006b). These observations may suggest that the spatial boundaries of the region could be reconsidered, possibly in conjunction with region 6. However, data from these two regions are more limited than for other areas and are probably insufficient to support further refinement of the regional boundaries.

In general, temporal trends in the aggregated size composition for an entire region are consistent between the length and weight data sets. However, for those regions where there is considerable within-region variation in fish size (region 3 and 5), some temporal variation between the aggregated length and weight data was observed. This was attributable to differences in the spatial distribution of the sampling for lengths and weights. For example, during a period more length samples may be collected from an area which is generally comprised of smaller fish compared to the collection of weight samples, thereby, resulting in a lower overall fish size comprising the length composition.

The assessment models incorporate the (aggregated) size frequency data as the observed size composition of the catch from the specific fishery. Differences in the spatial distribution of sampling (for length or weight) may introduce a bias in the observed size composition data, particularly in cases where the spatial distribution of sampling is very different from the spatial distribution of the total catch. A detailed analysis of size data from region 3 indicated that, particularly for the length data, there was a considerable discrepancy between the distribution of sampling and catch especially since the mid 1980s (Langley 2006a). On this basis, it is appropriate to develop a methodology to derive an aggregate regional size composition that combines the size frequency data in proportion to the catch taken within each of the sub-areas of a region.

In the assessment models, the estimated size composition of the catch from a specific fishery is derived via the application of the fishery-specific age based selectivity function. Fishery-specific selectivity is assumed to be constant throughout the model period. However, for a number of fisheries, principally those within regions exhibiting spatial heterogeneity in the size data, this assumption is likely to be violated to some extent if the spatial distribution of the fishery (within the region) changes over time.

For the Japanese distant-water longline fleet, there appears to have been considerable shifts in the spatial distribution of fishing effort (and catch) over the history of the fishery. Such changes may result in substantial changes in the size composition of the catch even though the underlying size composition of the population hasn’t changed; by definition this represents a change in the selectivity of the fishery. For example, over the history of the Japanese distant-water longline fishery in region 3 there was a steady increase in the proportion of the yellowfin catch taken from the area approximating the FSM EEZ. The catch from this area is comprised of larger fish than other areas with the region (e.g. PNG waters) and, consequently, the true selectivity of the fishery is likely to have shifted towards slightly larger (older) fish over the history of the fishery. Therefore, the assumption of constant selectivity in the model is somewhat biased and may result in a bias of some of the other highly correlated parameters in the model, for example, the time series of recruitment parameters.

The qualitative analysis of the size data provides some interesting insights into the dynamics and exploitation of yellowfin and bigeye in the WCPO. The size data represents the summation of the recent trends in recruitment, growth and mortality (natural and fishing) mediated by the fishery specific selectivity function. Areas of consistently smaller fish are likely to be more dominated by recent recruitment and, therefore, likely to be closer to key spawning areas for the species. For yellowfin, fish tend to be smaller in the western equatorial area and increase in size eastward and with increasing latitude. This is consistent with increased spawning activity in the western equatorial region and a diffusion of fish outwards from this area.

Systematic declining trends in fish size throughout adjacent areas are more likely to be attributable to increasing mortality rates in the population, including those induced by fishing. For yellowfin, such trends were evident in the size composition of the catch from the eastern equatorial region (region 4) and Coral Sea/Tasman Sea (region 5), principally during the early period of the fishery (1950s to 1970s). The reduction in the proportion of the large fish from the populations in these areas indicates that fishing mortality was exceeding the rate of replenishment through diffusion and growth. Over the history of the fishery, the spatial differences in the size composition of the yellowfin longline catch throughout these three regions has converged and is considerably more homogeneous than during the early period of the fishery.

For bigeye tuna, there was a steady and consistent decline in fish size throughout regions 2, 4, and 5 between the 1950s and 1980. This may represent a steady increase in fishing mortality throughout the period. In contrast, fish size has remained relatively stable during the subsequent period. As with yellowfin, bigeye size remained relatively stable within region 3, with the exception of the recent sharp decline in fish size in the South China Sea/Philippines Sea. There is also a higher proportion of smaller bigeye in the northern waters of the PNG EEZ and this area may be of importance for spawning and/or as a nursery ground for bigeye tuna.

Clearly, the size frequency data provides some insights into the ecology of the two species and the impact of fishing on the stock. However, any quantification of the impacts of fishing is reliant on the inclusion of these data in an assessment model that accurately captures the main dynamics of the population. The analysis presented in this paper is intended to guide the structural aspects of such a model.

5. References

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Table 1. Definition of fisheries for the 2005 MULTIFAN-CL analysis of WCPO bigeye and yellowfin tuna and the number of fish weight measurements.

Fishery Number	Reference Code	Nationality	Gear	Region	Number of fish sampled for weight	
					YFT	BET
1	LL ALL 1	Japan, Korea, Chinese Taipei	Longline	1	845,265	928,425
2	LL ALL 2	Japan, Korea, Chinese Taipei	Longline	2	40,309	191,677
3	LL HW 2	United States (Hawaii)	Longline	2	0	0
4	LL ALL 3	All excl. Chinese Taipei & China	Longline	3	2,479,224	1,756,231
5	LL TW-CH 3	Chinese Taipei and China	Longline	3	1,117,578	496,537
6	LL PG 3	Papua New Guinea	Longline	4	129,155	31,245
7	LL ALL 4	Japan, Korea	Longline	4	353,212	412,308
8	LL TW-CH 4	Chinese Taipei and China	Longline	4	0	0
9	LL HW 4	United States (Hawaii)	Longline	4	161,376	526,367
10	LL ALL 5	All excl. Australia	Longline	5	213,285	60,610
11	LL AU 5	Australia	Longline	5	311,995	145,892
12	LL ALL6	Japan, Korea, Chinese Taipei	Longline	6	2,102	2,598
13	LL PI 6	Pacific Island Countries/Territories	Longline	6	28	59
14	PS ASS 3	All	Purse seine, log/FAD sets	3	0	0
15	PS UNS 3	All	Purse seine, school sets	3	0	0
16	PS ASS 4	All	Purse seine, log/FAD sets	4	0	0
17	PS UNS 4	All	Purse seine, school sets	4	0	0
18	PHID MISC 3	Philippines, Indonesia	Miscellaneous (small fish)	3	0	0
19	PH HL 3	Philippines, Indonesia	Handline (large fish)	3	0	0
20	HL HW 4	United States (Hawaii)	Handline	4	NA	67,898

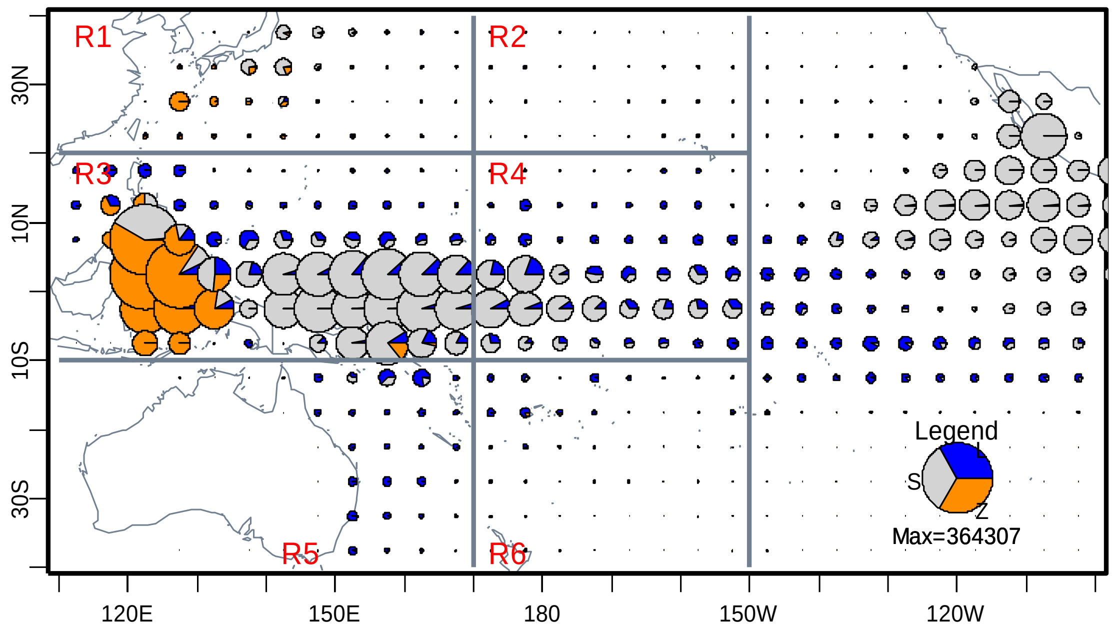

Figure 1. Definition of the six regions included in the 2005 stock assessment of yellowfin and bigeye in the WCPO.

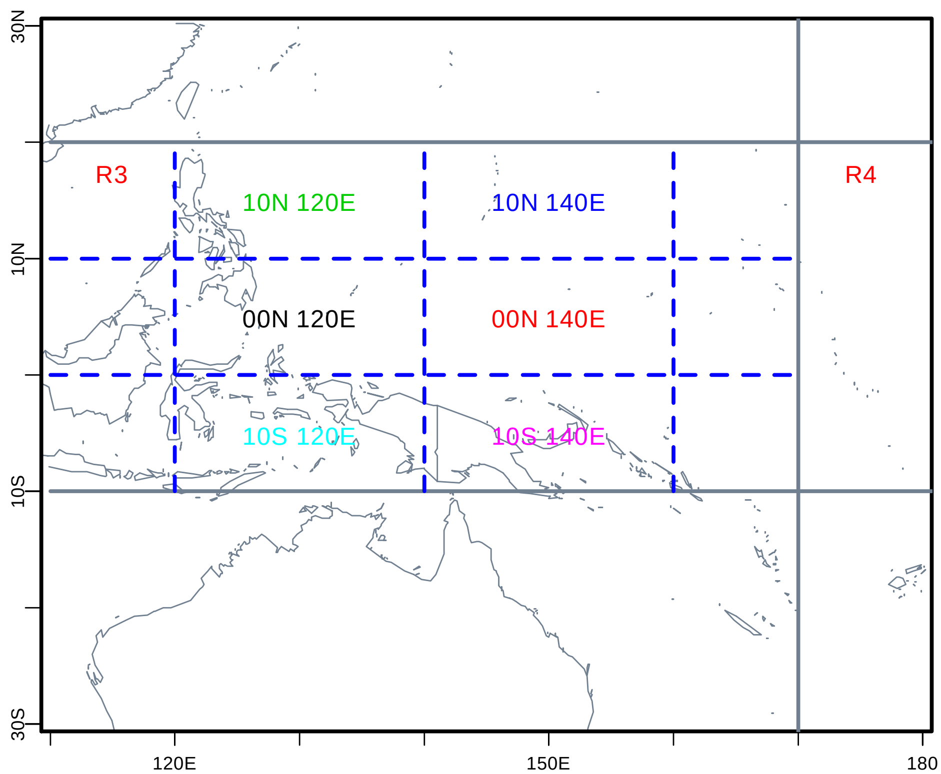

Figure 2. An example of the subdivision of an MFCL model region (3) into spatial blocks of 10 degrees of latitude and 20 degrees of longitude .

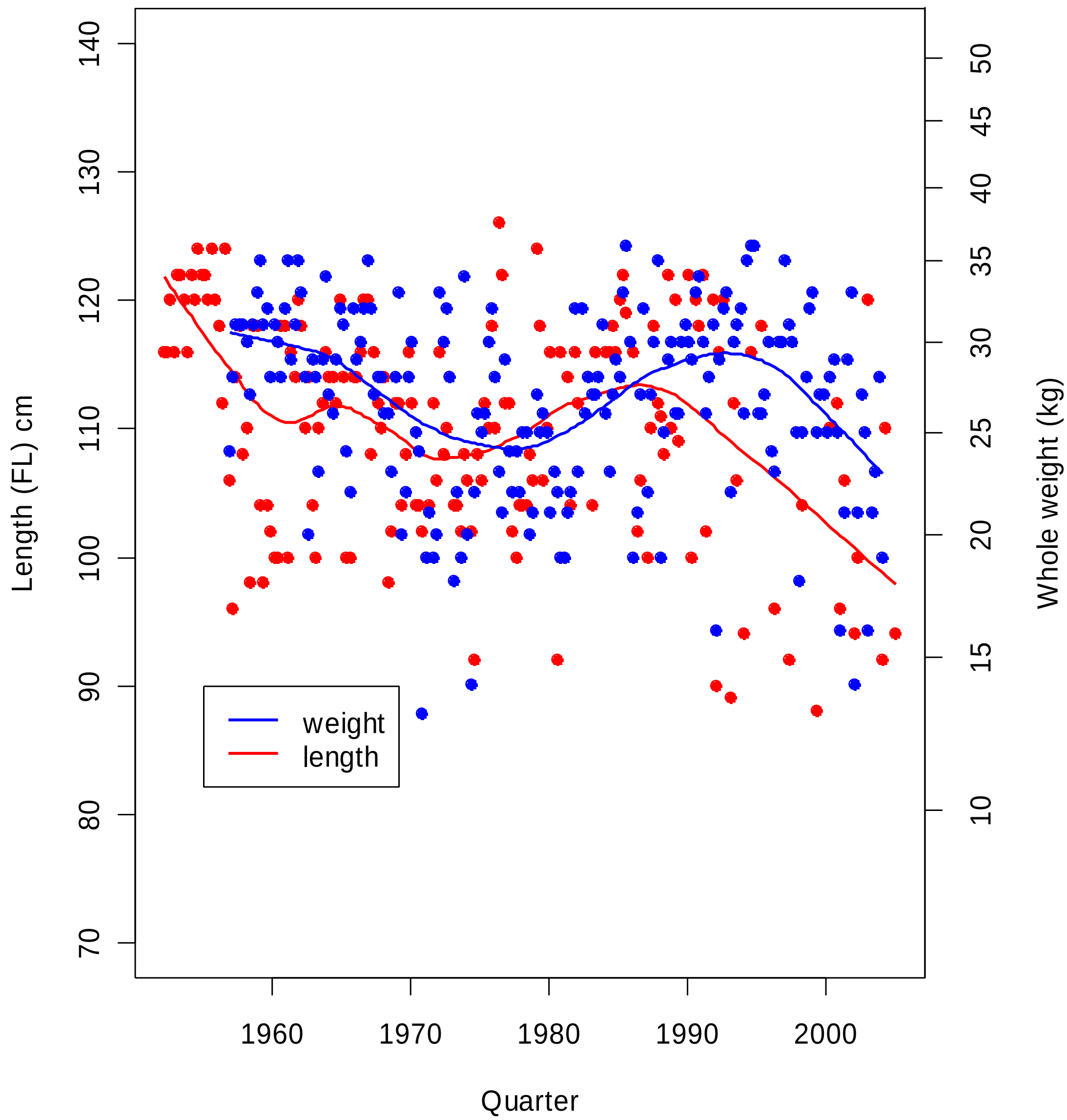

Figure 3. Median length (fork length) and weight (whole weight) of yellowfin sampled from the Japanese distant-water longline fishery operating in MFCL region 3, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

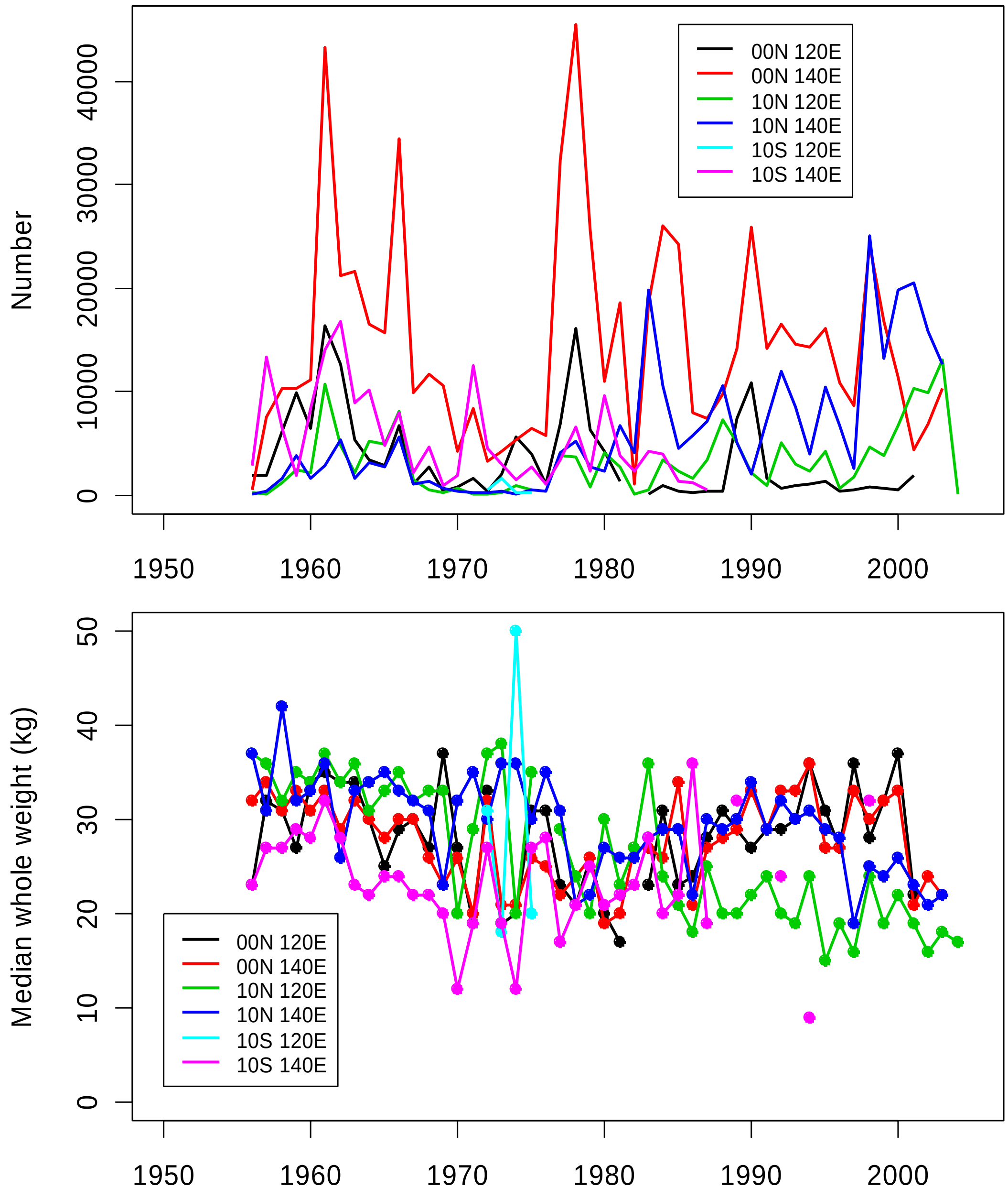

Figure 4. Annual number of yellowfin weights sampled (top) and median yellowfin weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 3. The blocks are defined by the location of the southwestern corner.

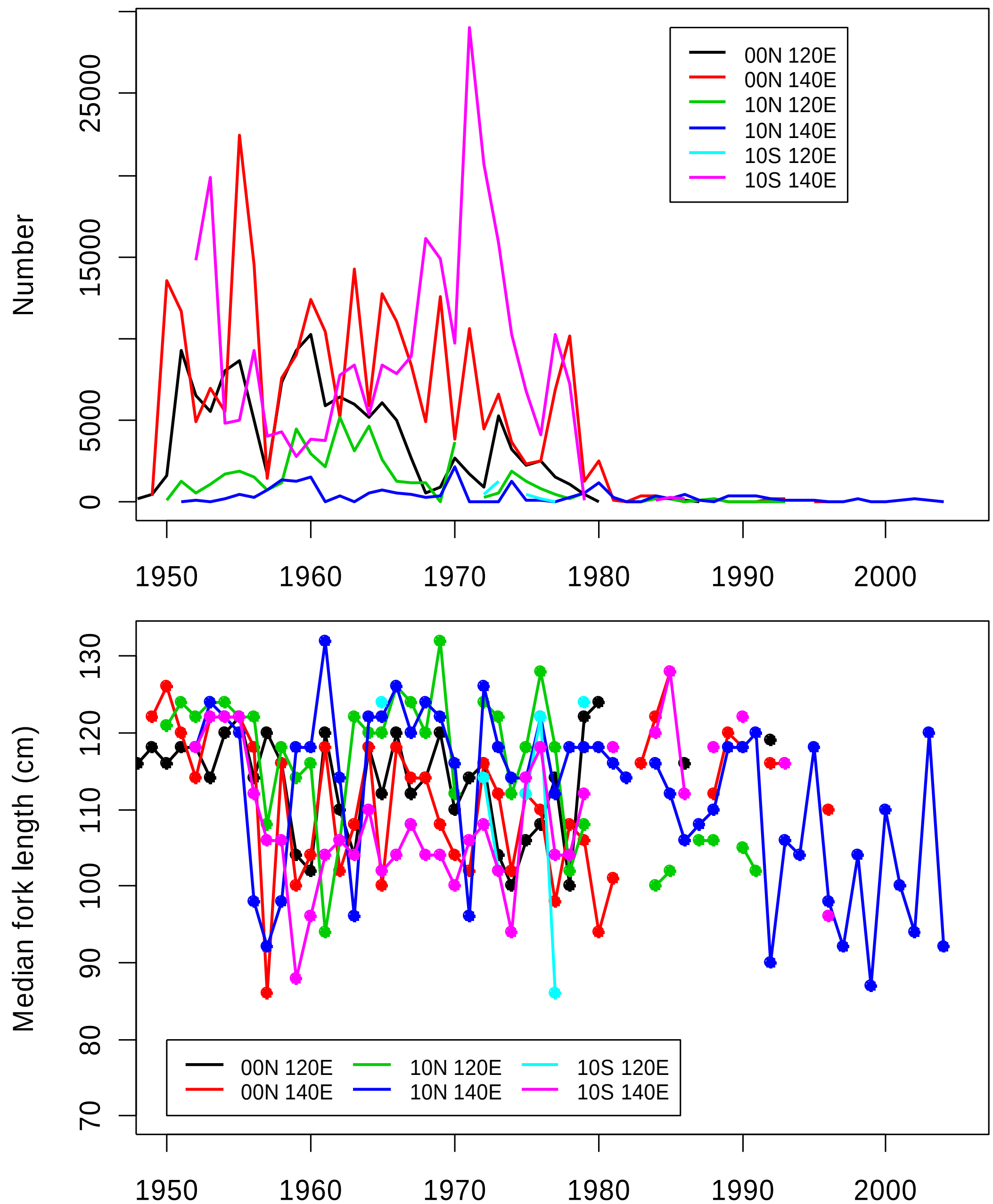

Figure 5. Annual number of yellowfin lengths sampled (top) and median yellowfin length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 3. The blocks are defined by the location of the southwestern corner.

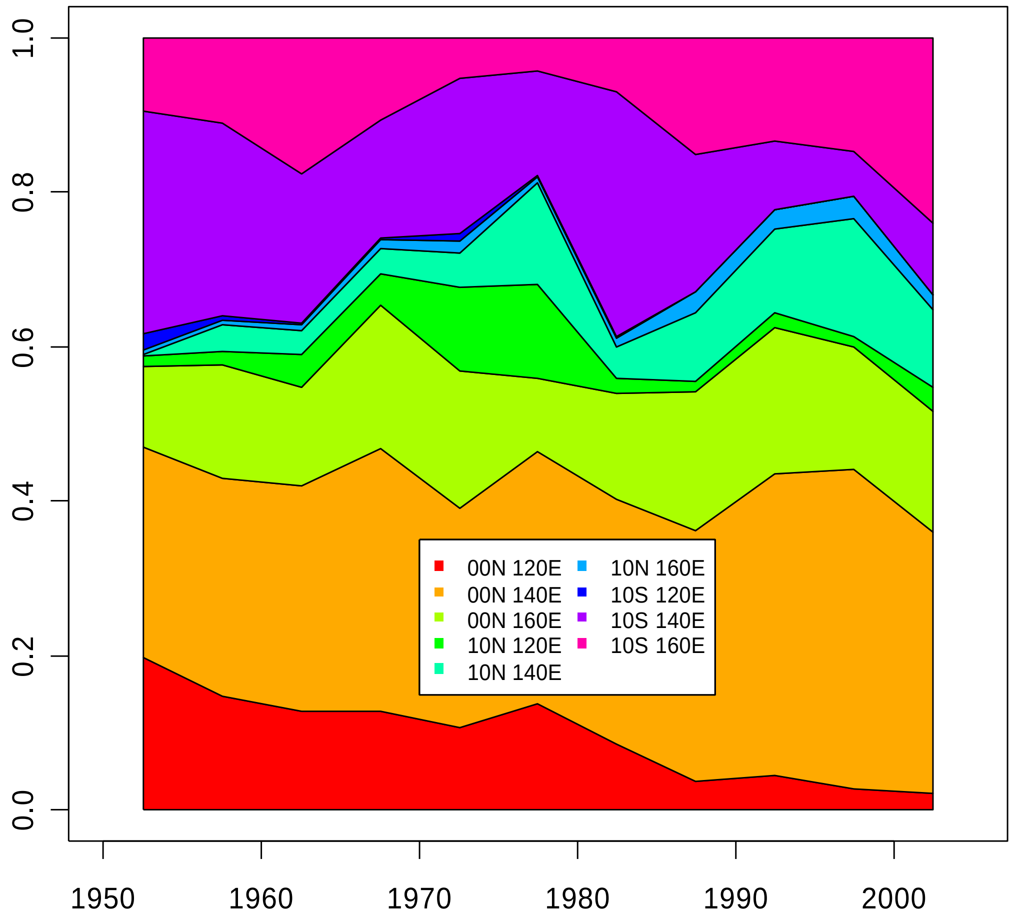

Figure 6. Proportional distribution of Japanese distant-water longline yellowfin catch (number of fish) by 10 degree latitude and 20 degree longitude squares comprising MFCL region 3 by 5-year intervals.

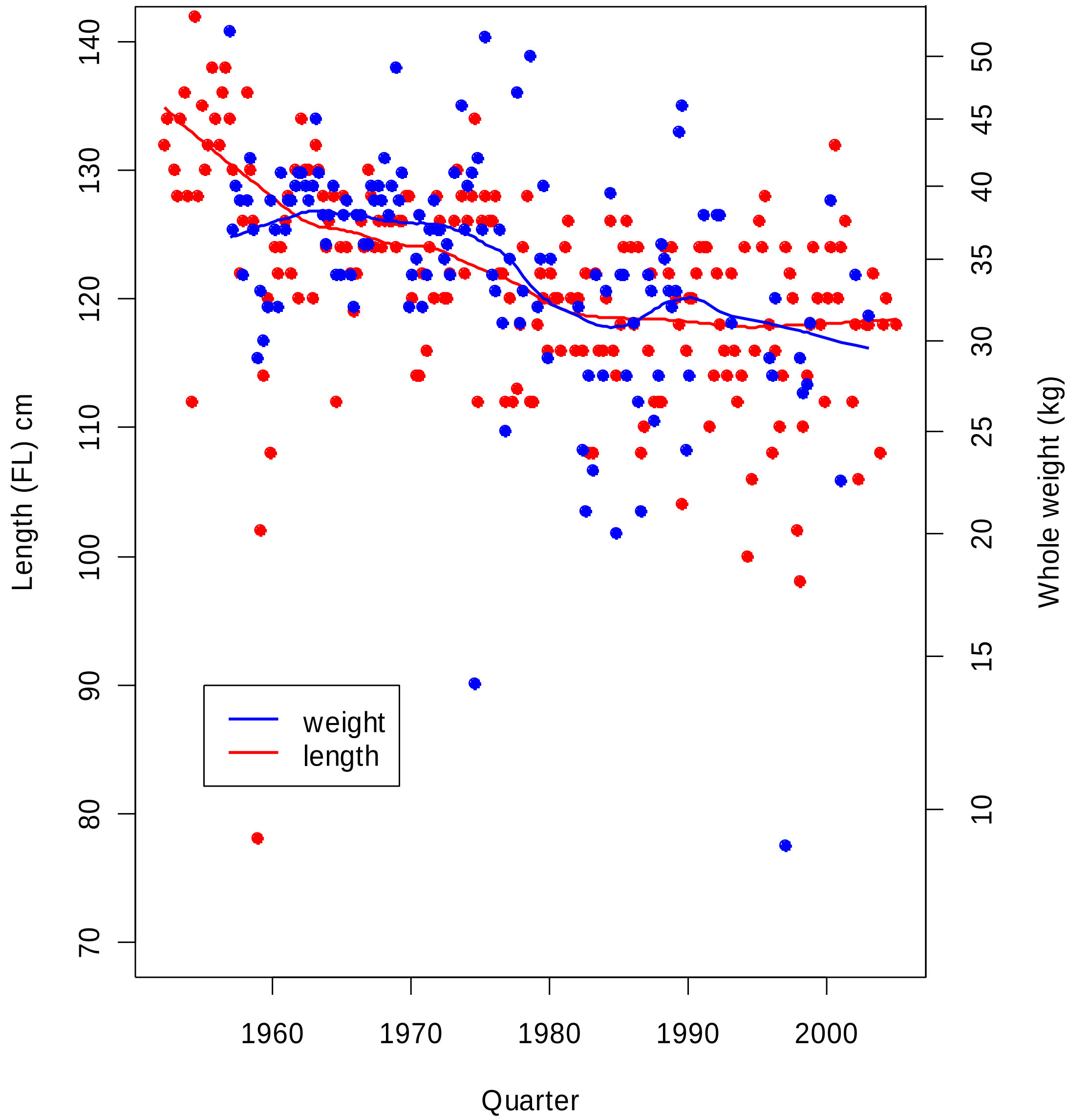

Figure 7. Median length (fork length) and weight (whole weight) of yellowfin sampled from the Japanese distant-water longline fishery operating in MFCL region 4, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

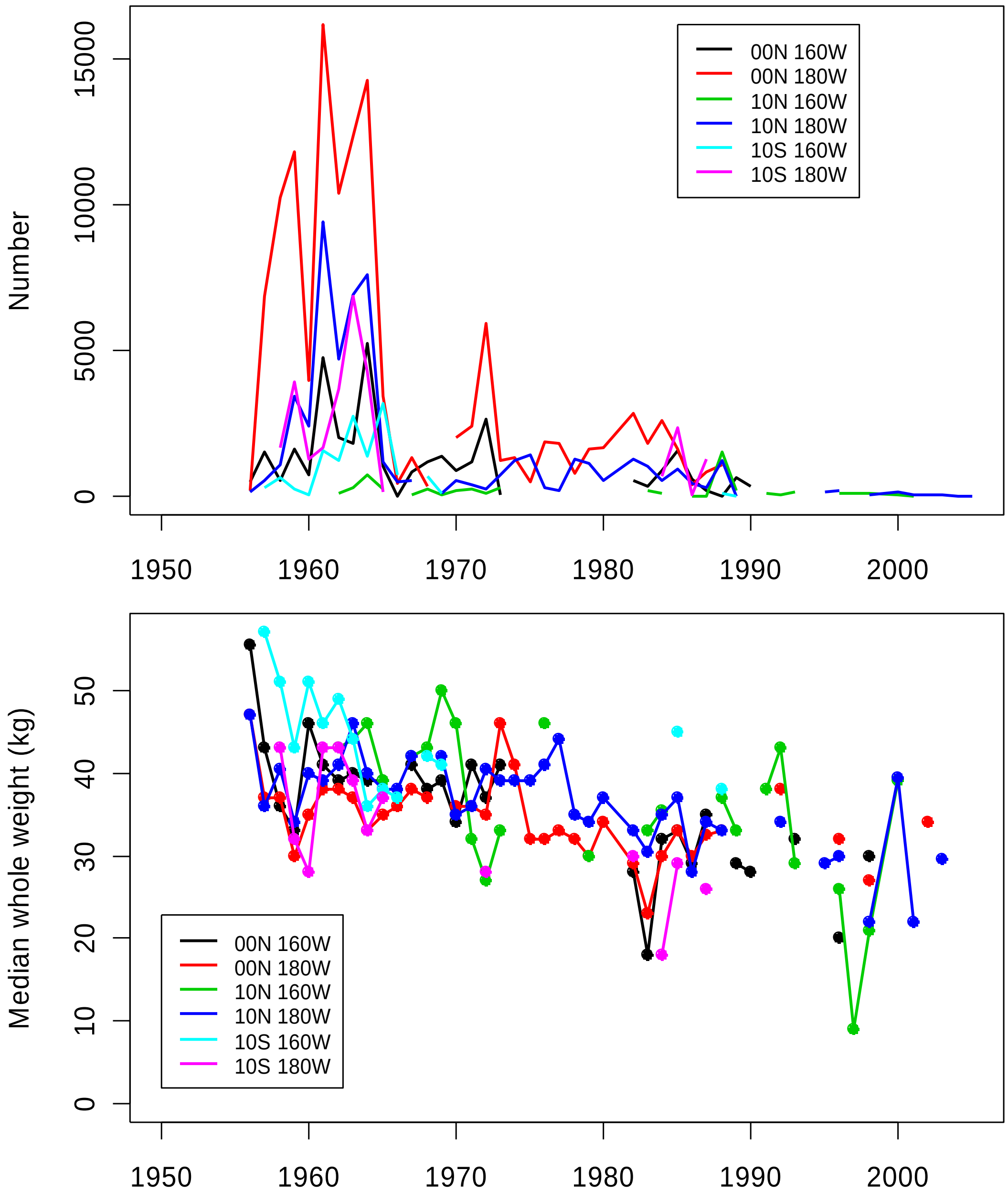

Figure 8. Annual number of yellowfin weights sampled (top) and median yellowfin weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 4. The blocks are defined by the location of the southwestern corner.

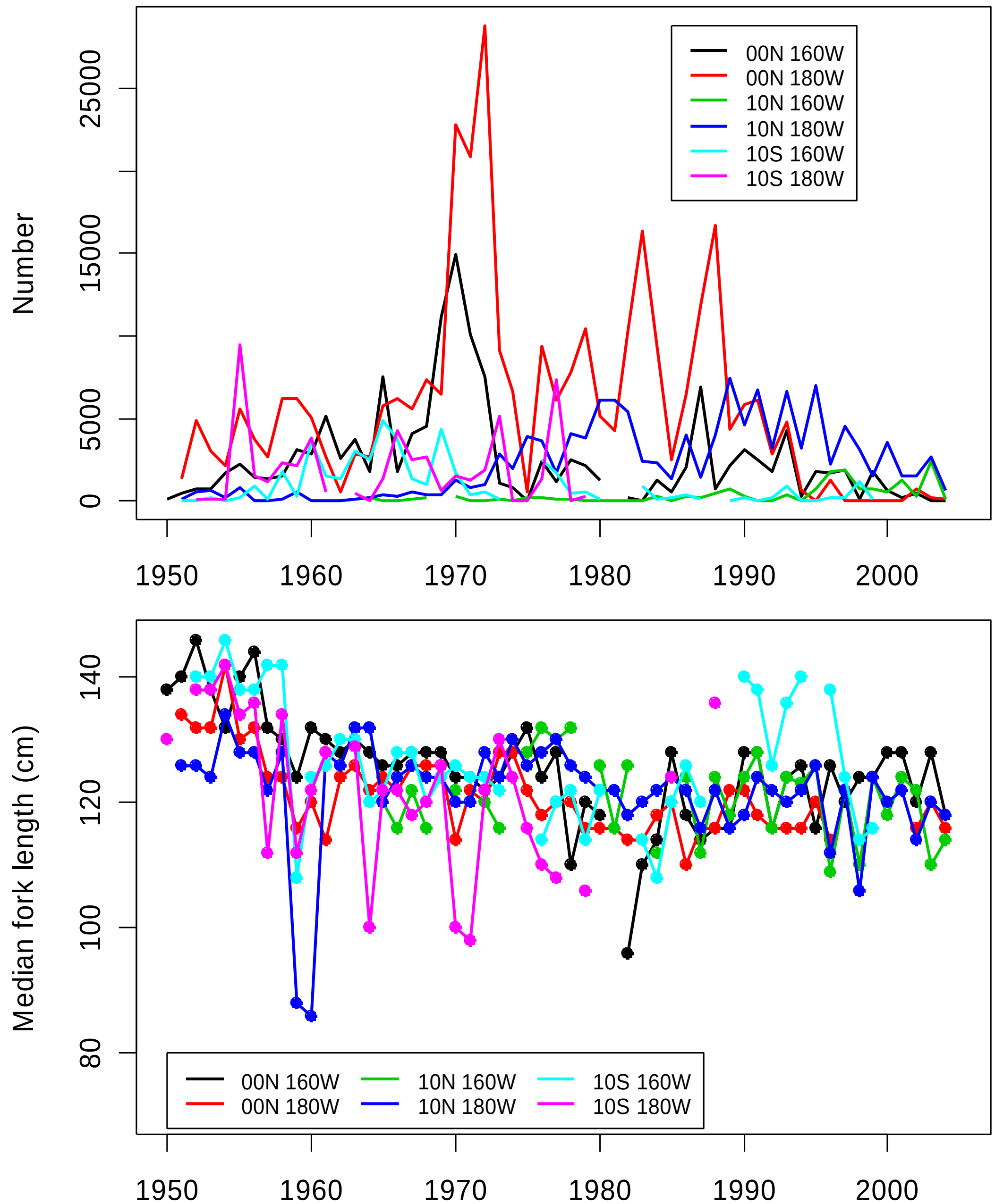

Figure 9. Annual number of yellowfin lengths sampled (top) and median yellowfin length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 4. The blocks are defined by the location of the southwestern corner.

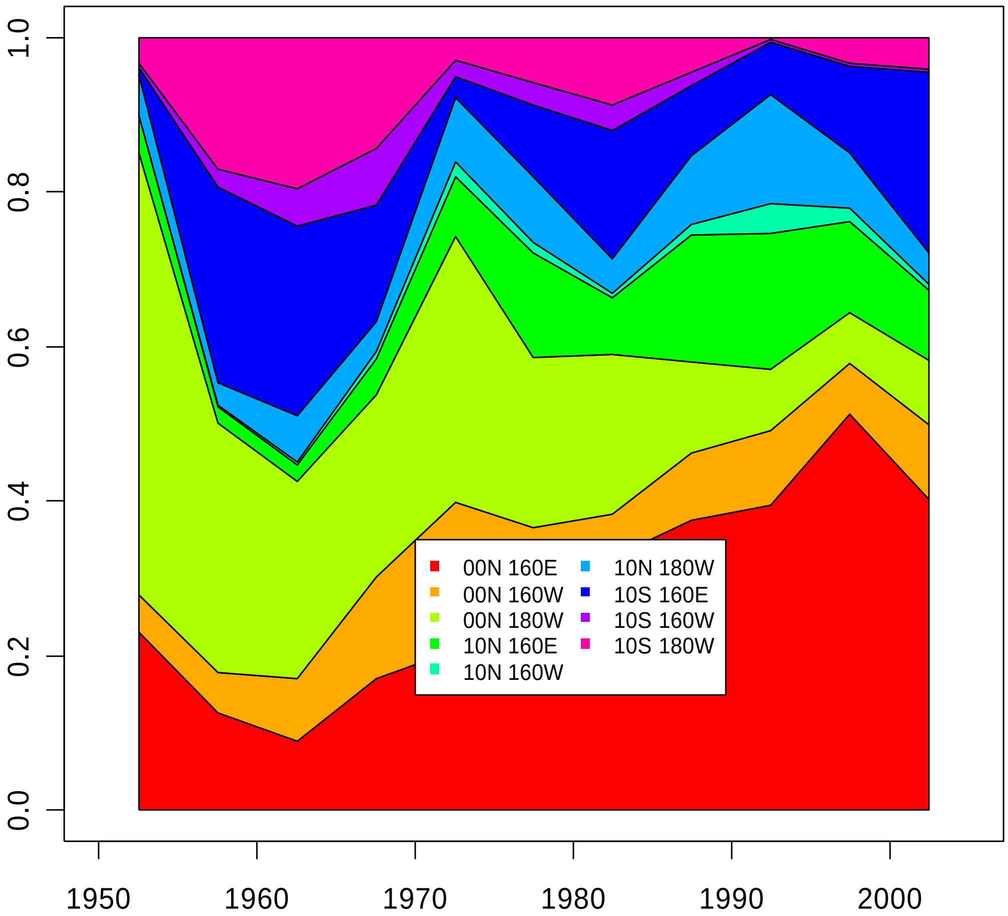

Figure 10. Proportional distribution of Japanese distant-water longline yellowfin catch (number of fish) by 10 degree latitude and 20 degree longitude squares comprising MFCL region 4 by 5-year intervals.

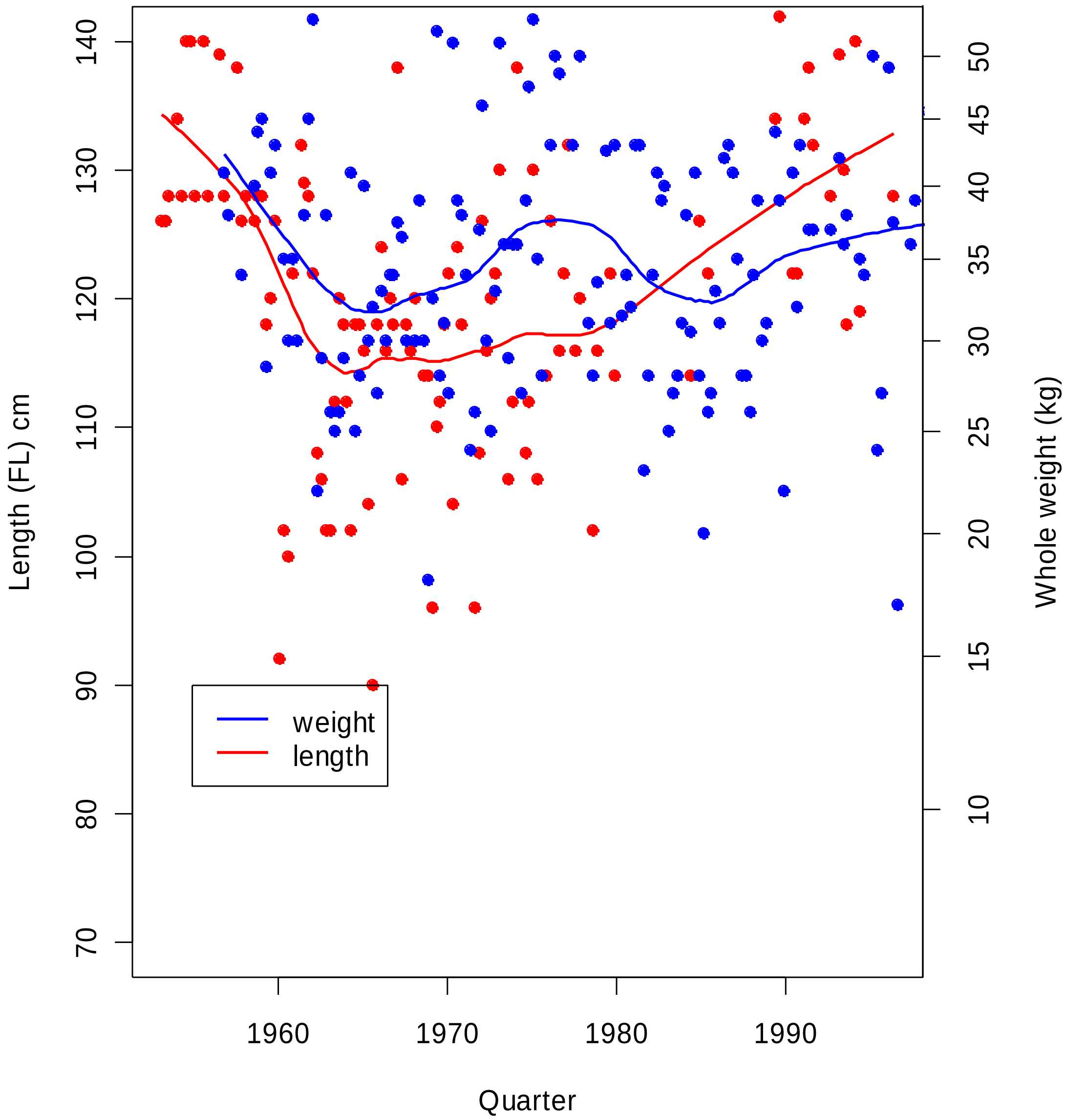

Figure 11. Median length (fork length) and weight (whole weight) of yellowfin sampled from the Japanese distant-water longline fishery operating in MFCL region 5, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

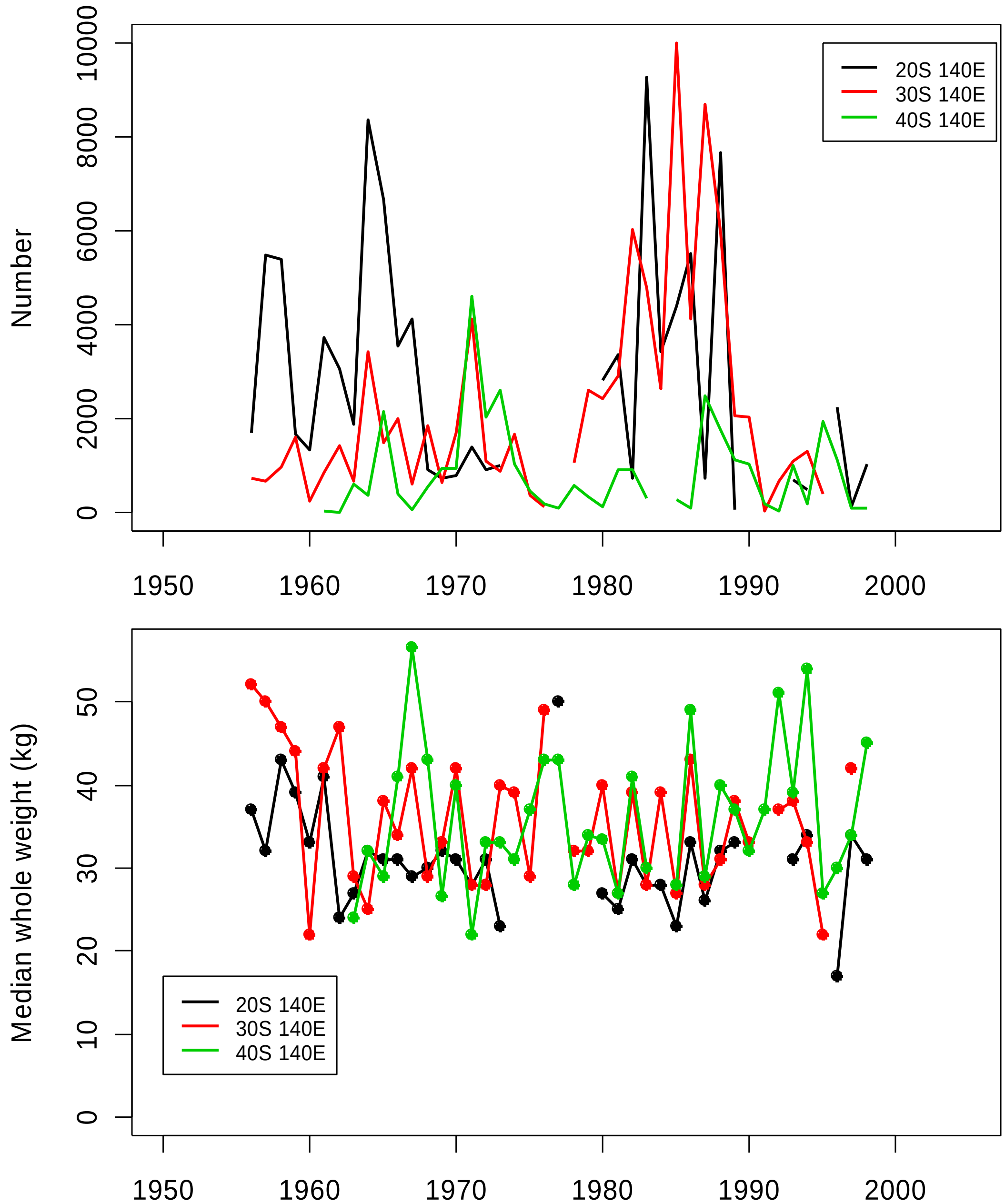

Figure 12. Annual number of yellowfin weights sampled (top) and median yellowfin weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 5. The blocks are defined by the location of the southwestern corner.

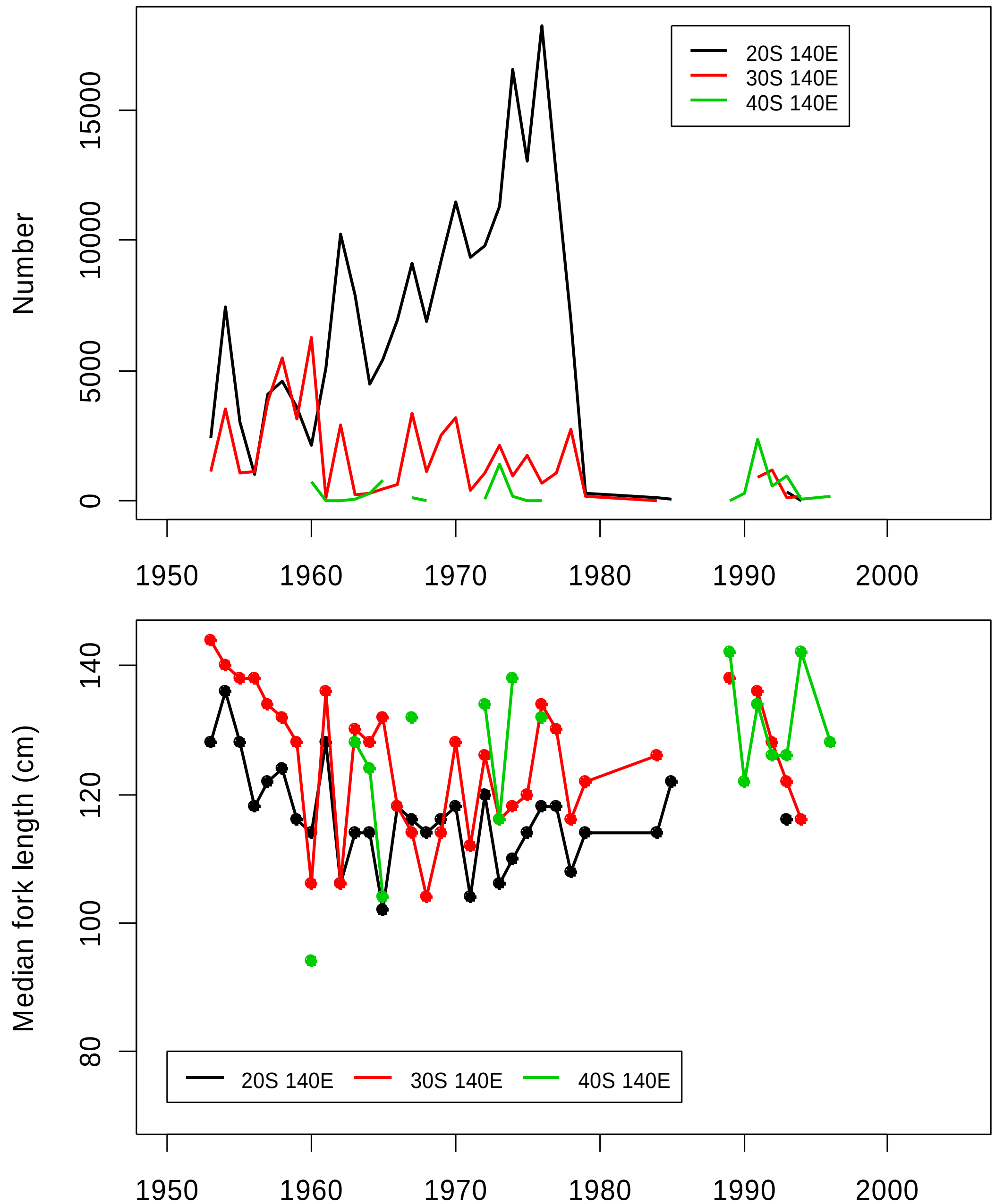

Figure 13. Annual number of yellowfin lengths sampled (top) and median yellowfin length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 5. The blocks are defined by the location of the southwestern corner.

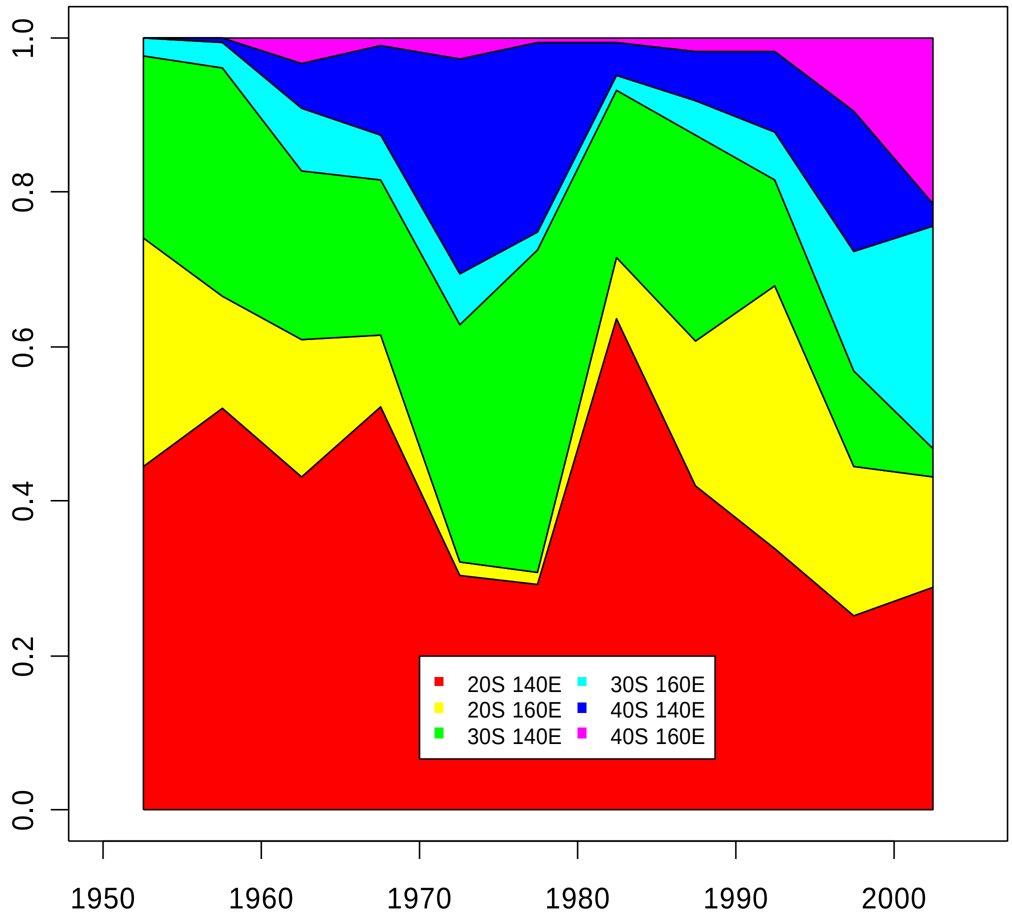

Figure 14. Proportional distribution of Japanese distant-water longline yellowfin catch (number of fish) by 10 degree latitude and 20 degree longitude squares comprising MFCL region 5 by 5-year intervals.

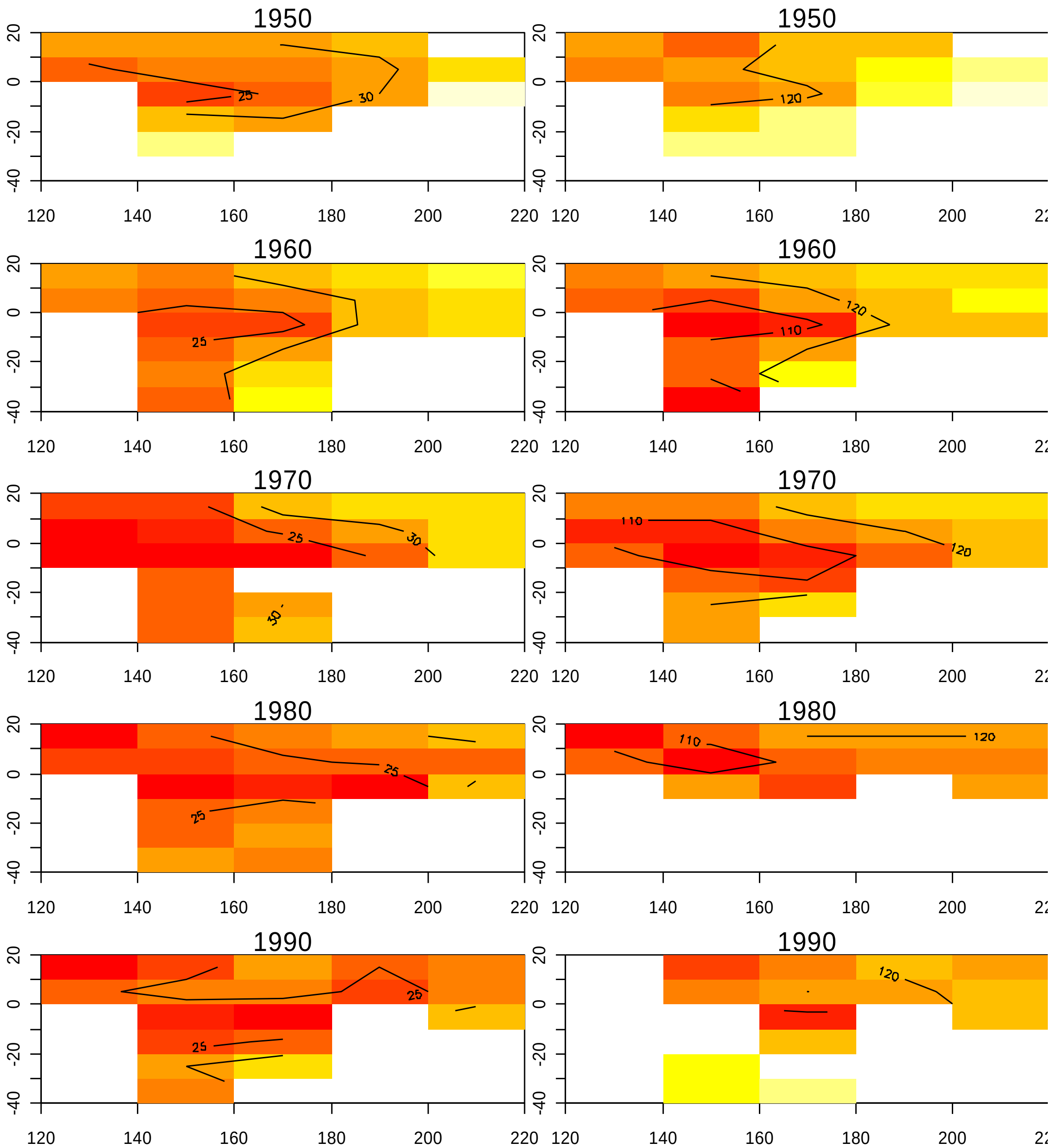

Figure 15. Spatial trends in the median weight (left) and median length (right) for longline caught yellowfin in the WCPO by decade. The decades are labeled by the first year of the decade. The colour scale denotes small (red) to large fish (yellow). The lines represent contour lines of weight (25 kg, 30 kg) and length (110 cm, 120 cm).

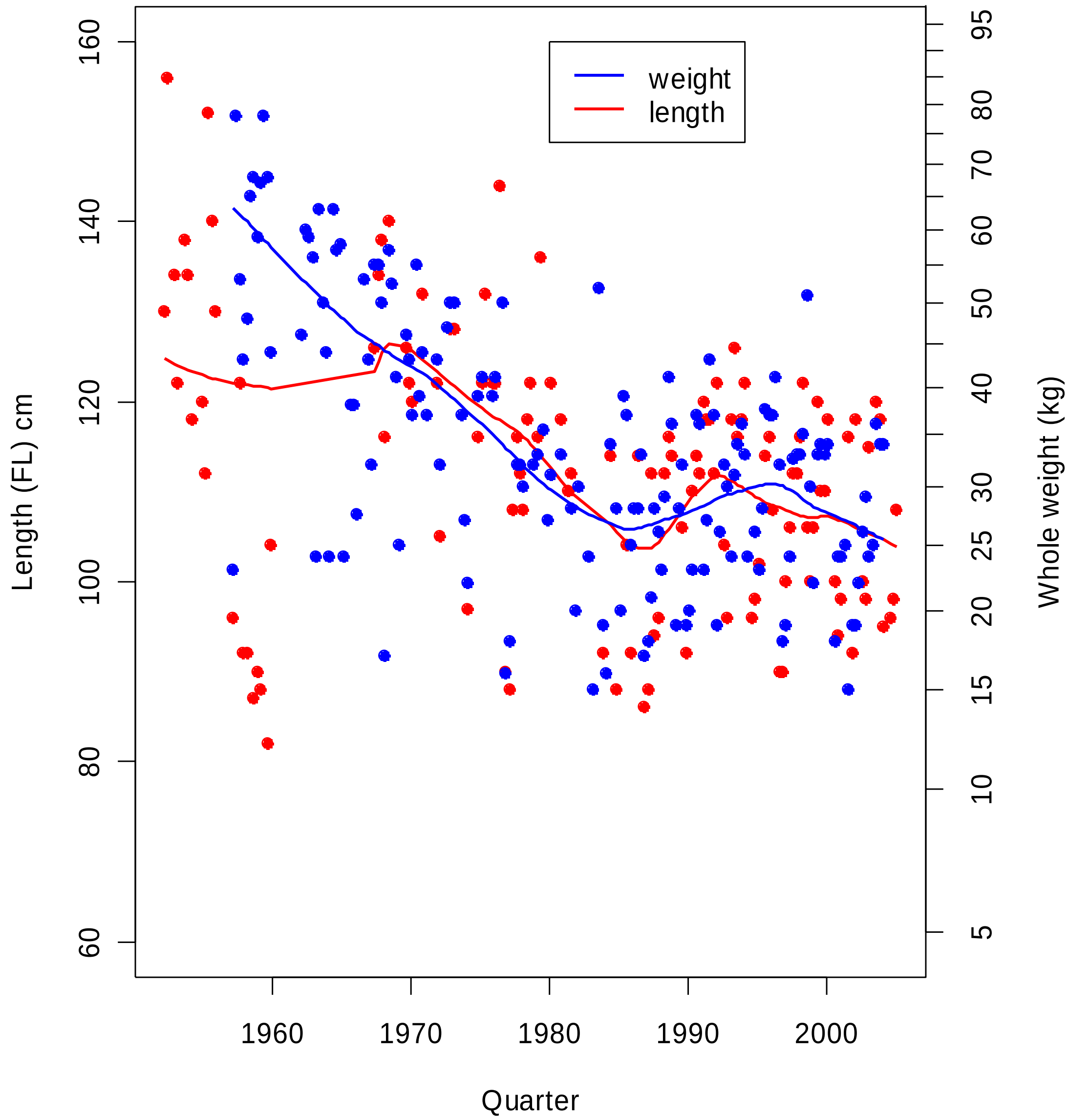

Figure 16. Median length (fork length) and weight (whole weight) of bigeye sampled from the Japanese distant-water longline fishery operating in MFCL region 2, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

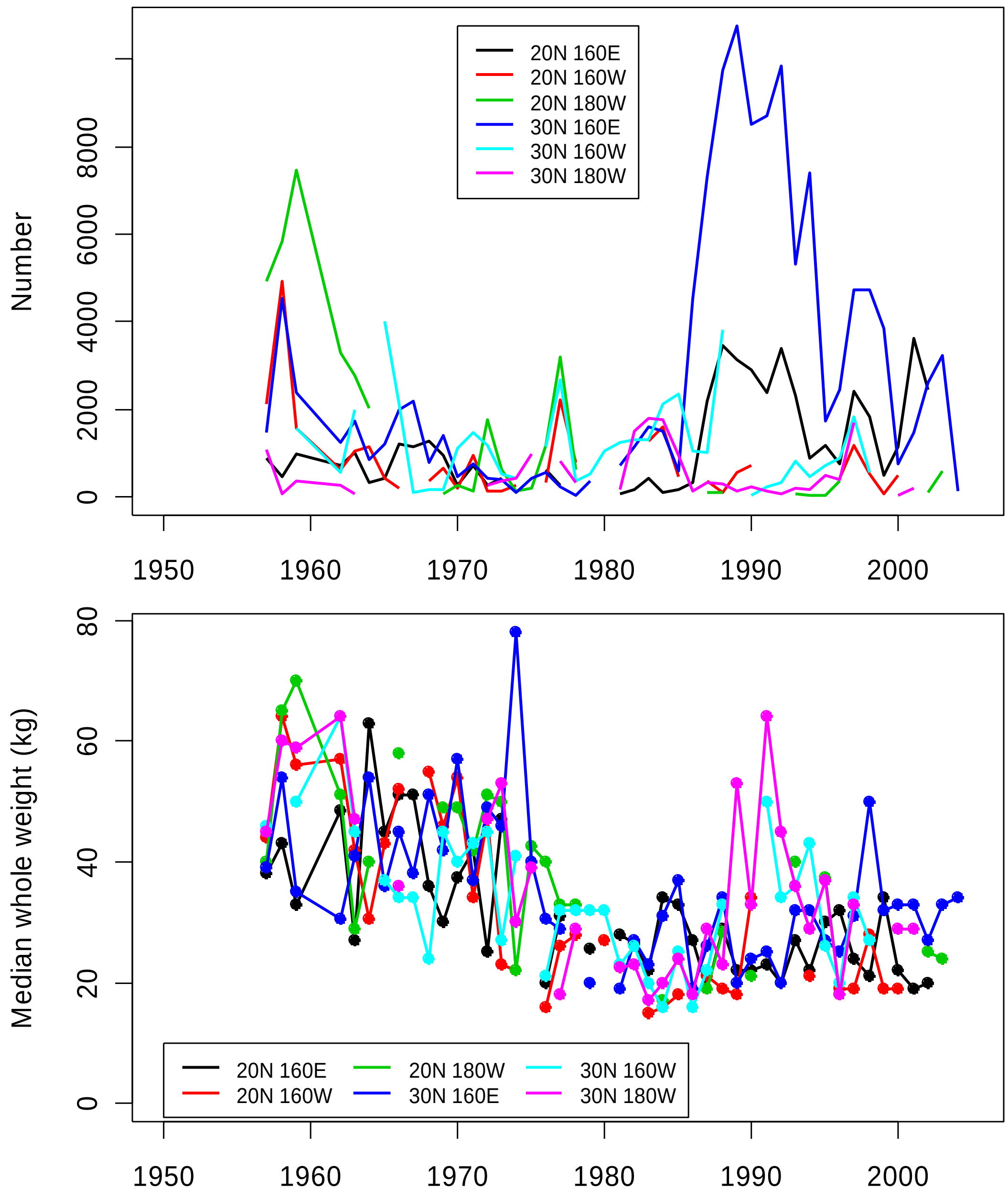

Figure 17. Annual number of bigeye weights sampled (top) and median bigeye weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 2. The blocks are defined by the location of the southwestern corner.

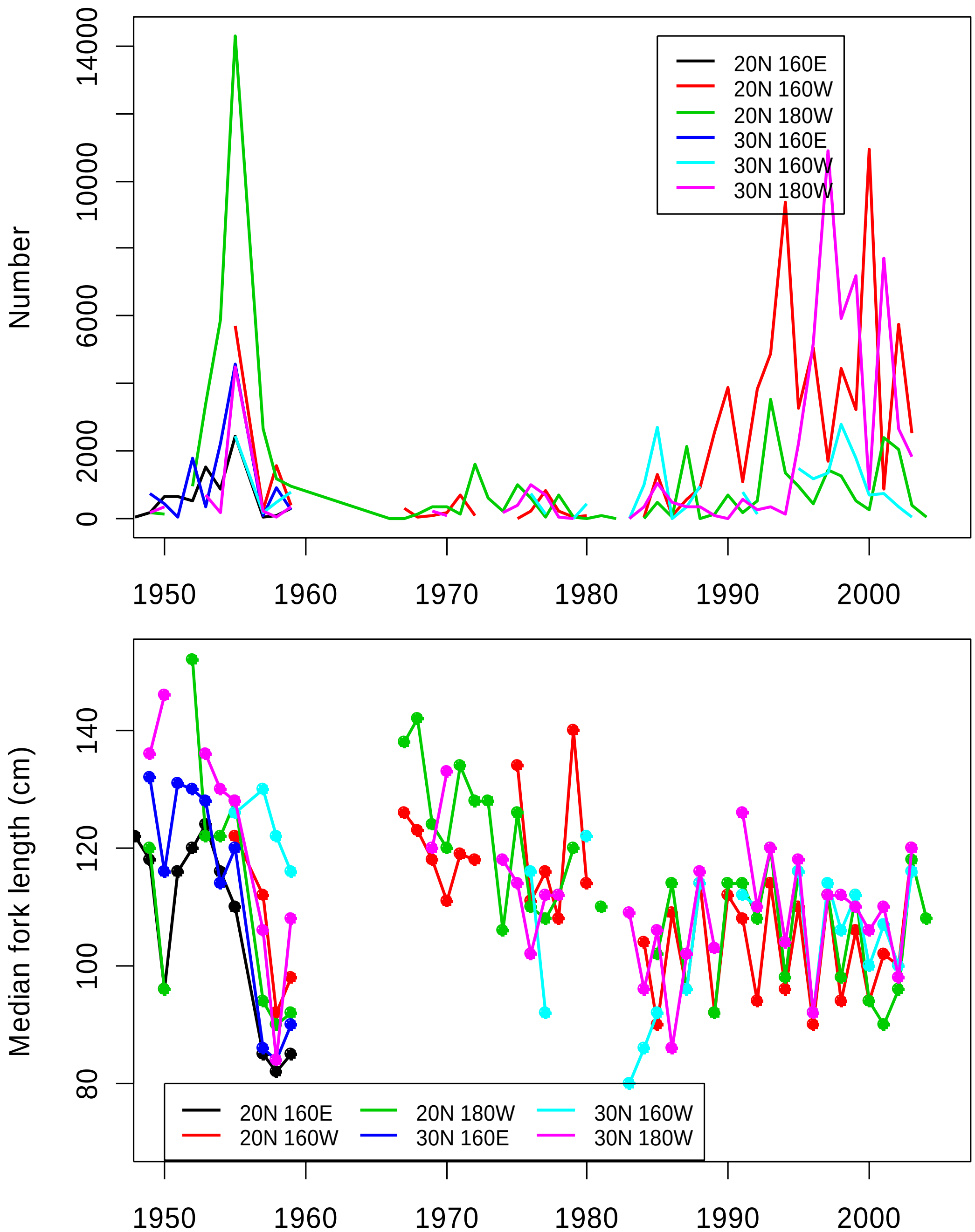

Figure 18. Annual number of bigeye lengths sampled (top) and median bigeye length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 2. The blocks are defined by the location of the southwestern corner.

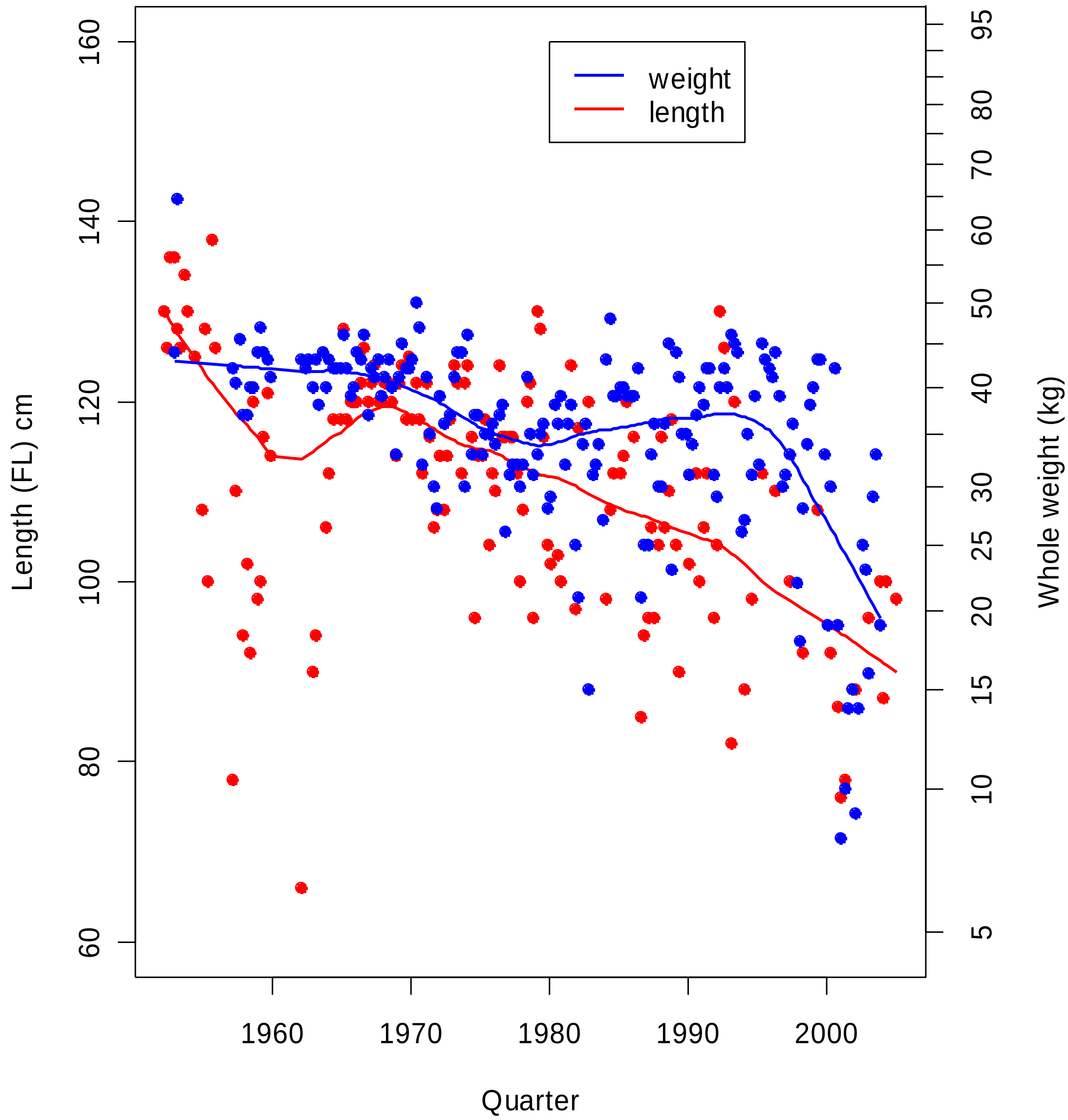

Figure 19. Median length (fork length) and weight (whole weight) of bigeye sampled from the Japanese distant-water longline fishery operating in MFCL region 3, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

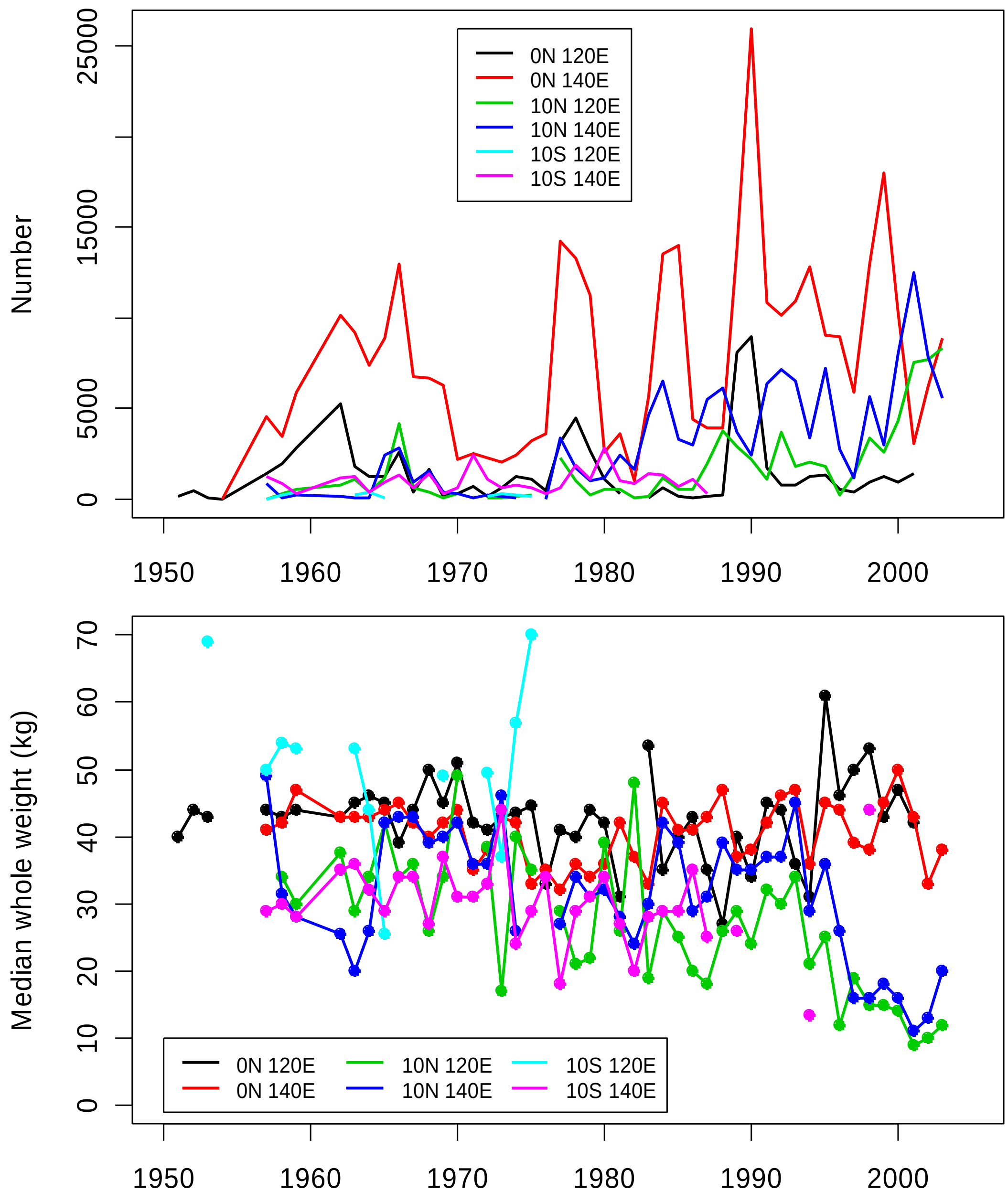

Figure 20. Annual number of bigeye weights sampled (top) and median bigeye weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 3. The blocks are defined by the location of the southwestern corner.

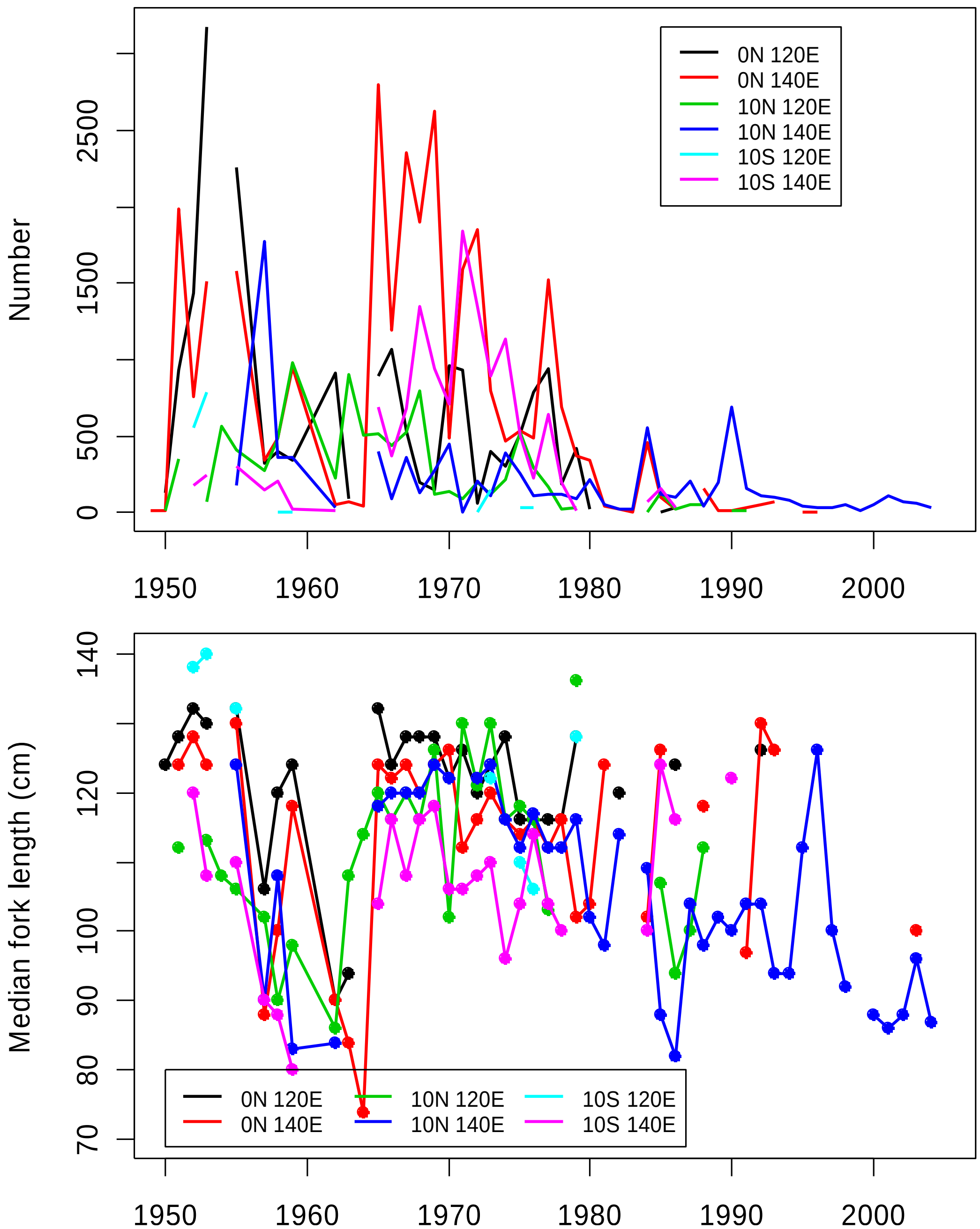

Figure 21. Annual number of bigeye lengths sampled (top) and median bigeye length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 3. The blocks are defined by the location of the southwestern corner.

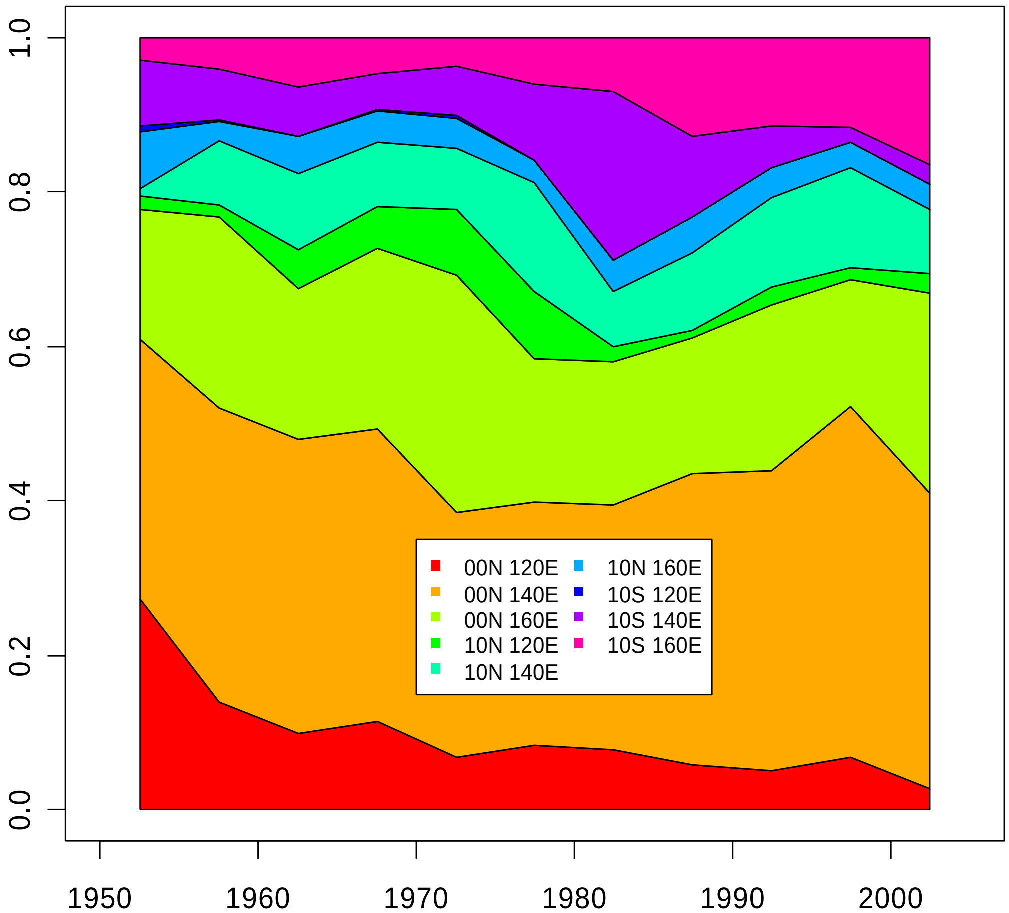

Figure 22. Proportional distribution of Japanese distant-water longline bigeye catch (number of fish) by 10 degree latitude and 20 degree longitude squares comprising MFCL region 3 by 5-year intervals.

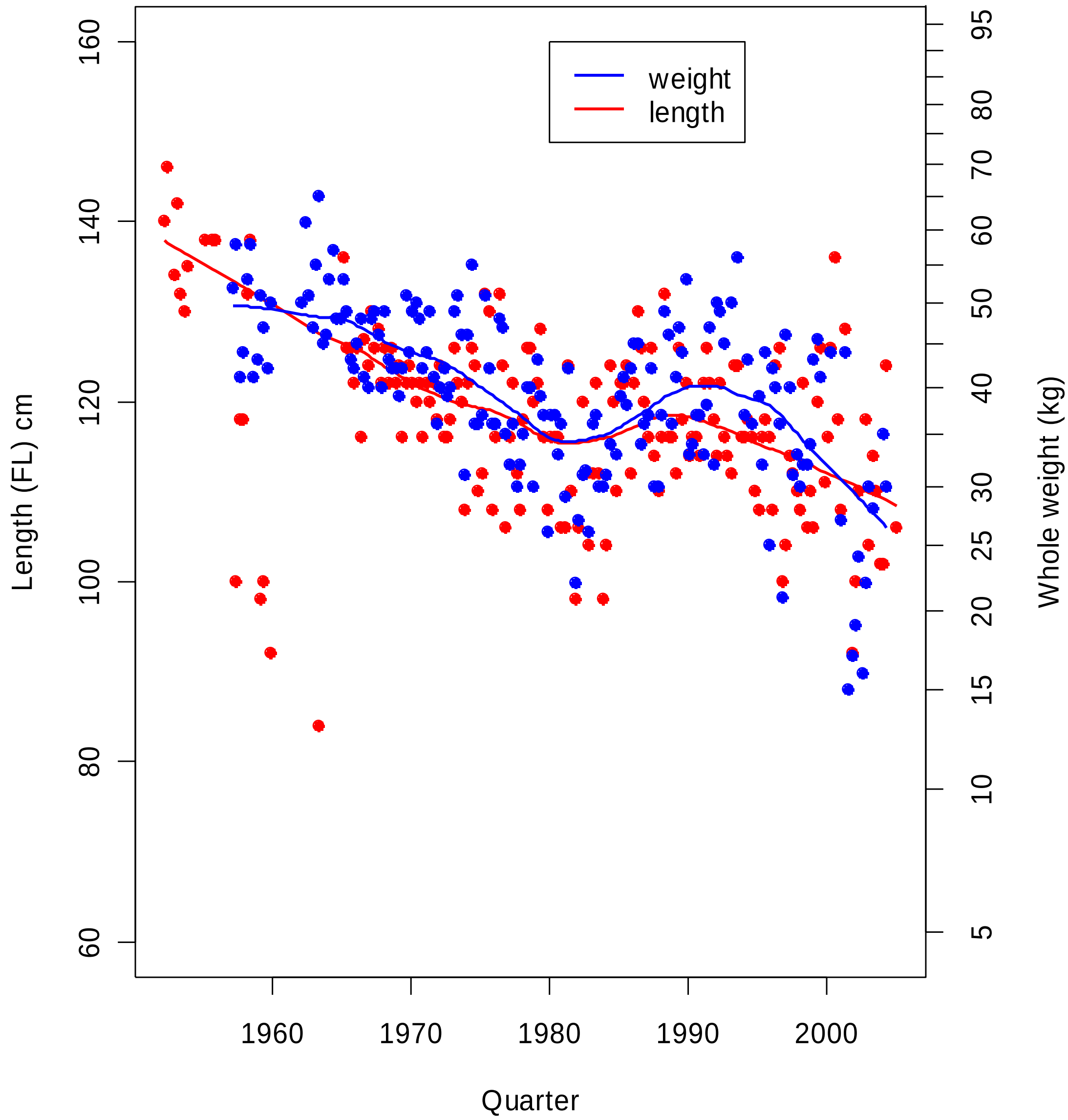

Figure 23. Median length (fork length) and weight (whole weight) of bigeye sampled from the Japanese distant-water longline fishery operating in MFCL region 4, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

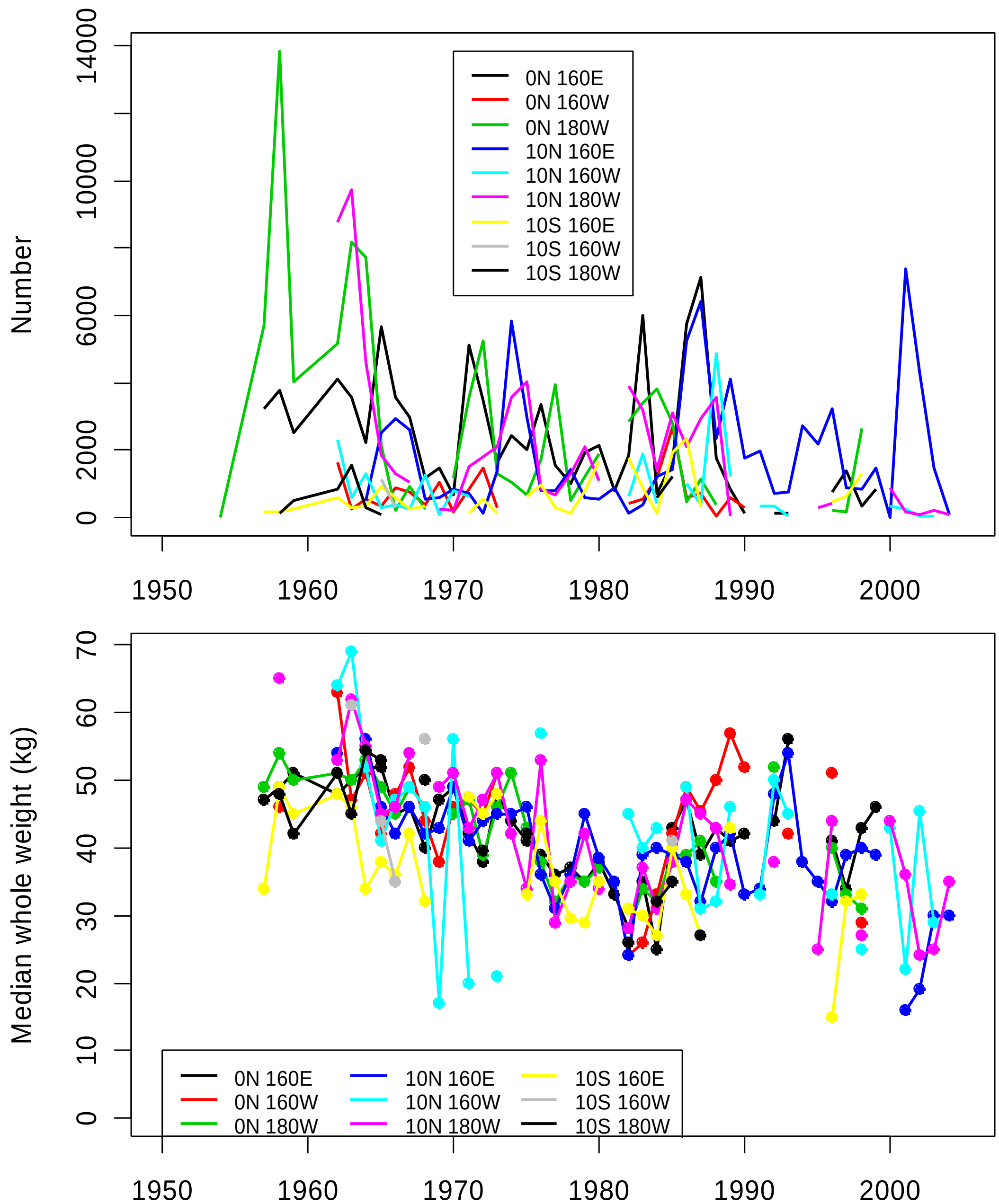

Figure 24. Annual number of bigeye weights sampled (top) and median bigeye weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 4. The blocks are defined by the location of the southwestern corner.

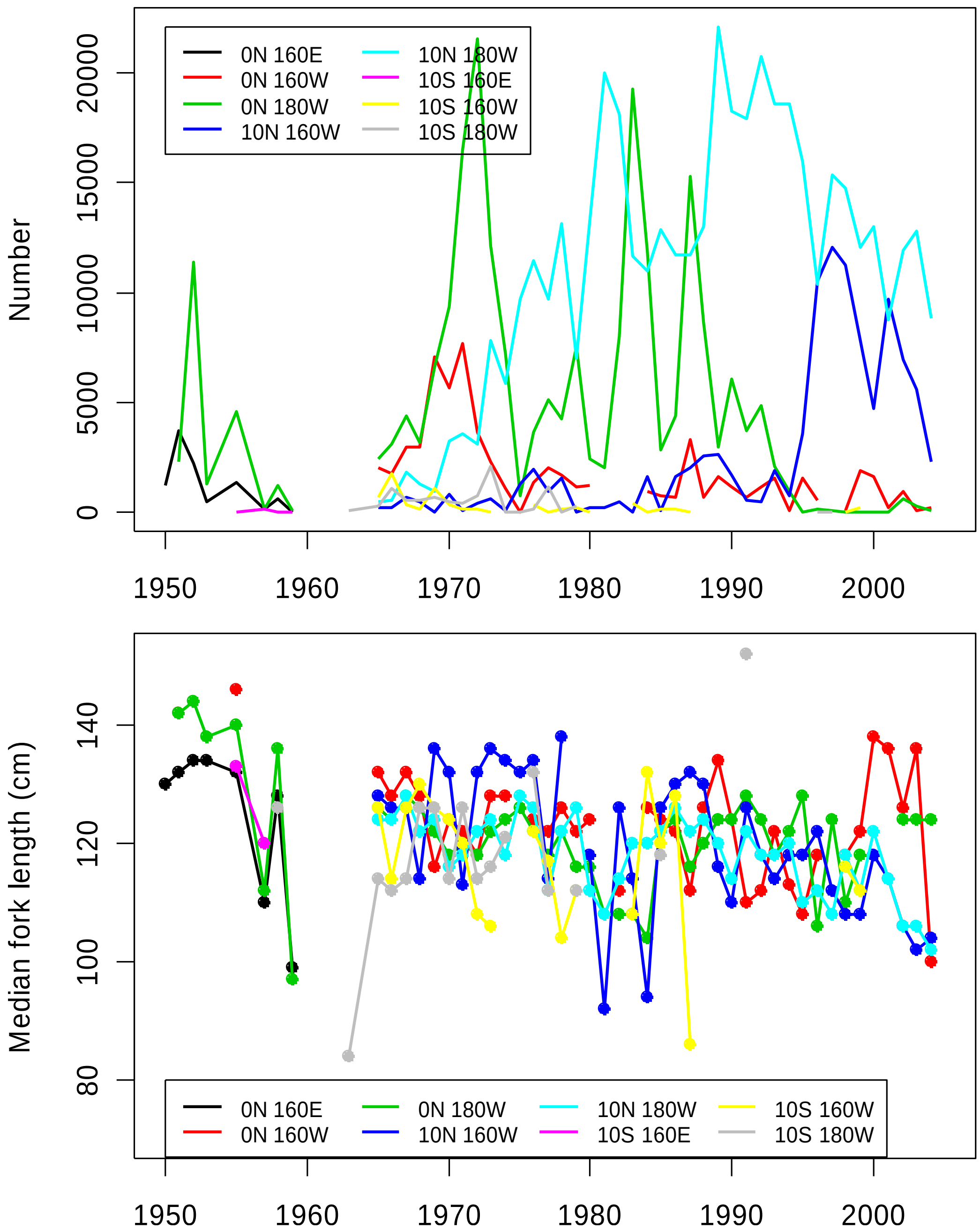

Figure 25. Annual number of bigeye lengths sampled (top) and median bigeye length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 4. The blocks are defined by the location of the southwestern corner.

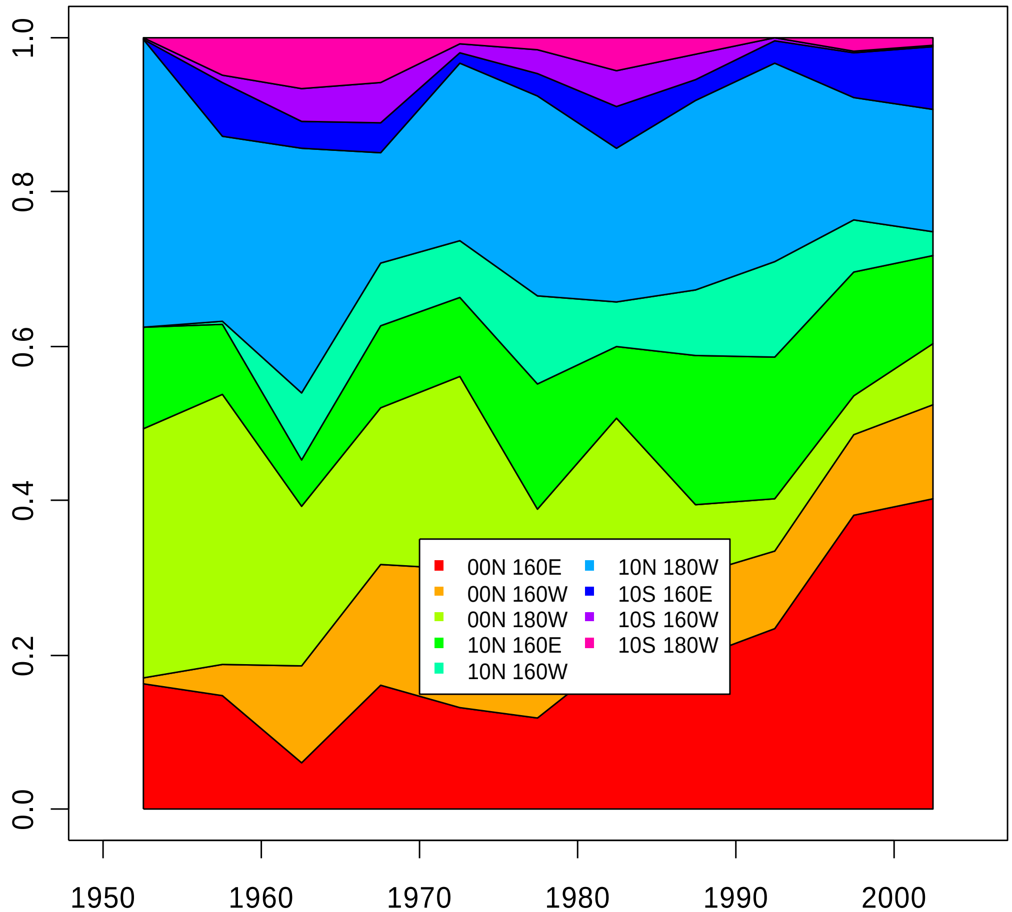

Figure 26. Proportional distribution of Japanese distant-water longline bigeye catch (number of fish) by 10 degree latitude and 20 degree longitude squares comprising MFCL region 4 by 5-year intervals.

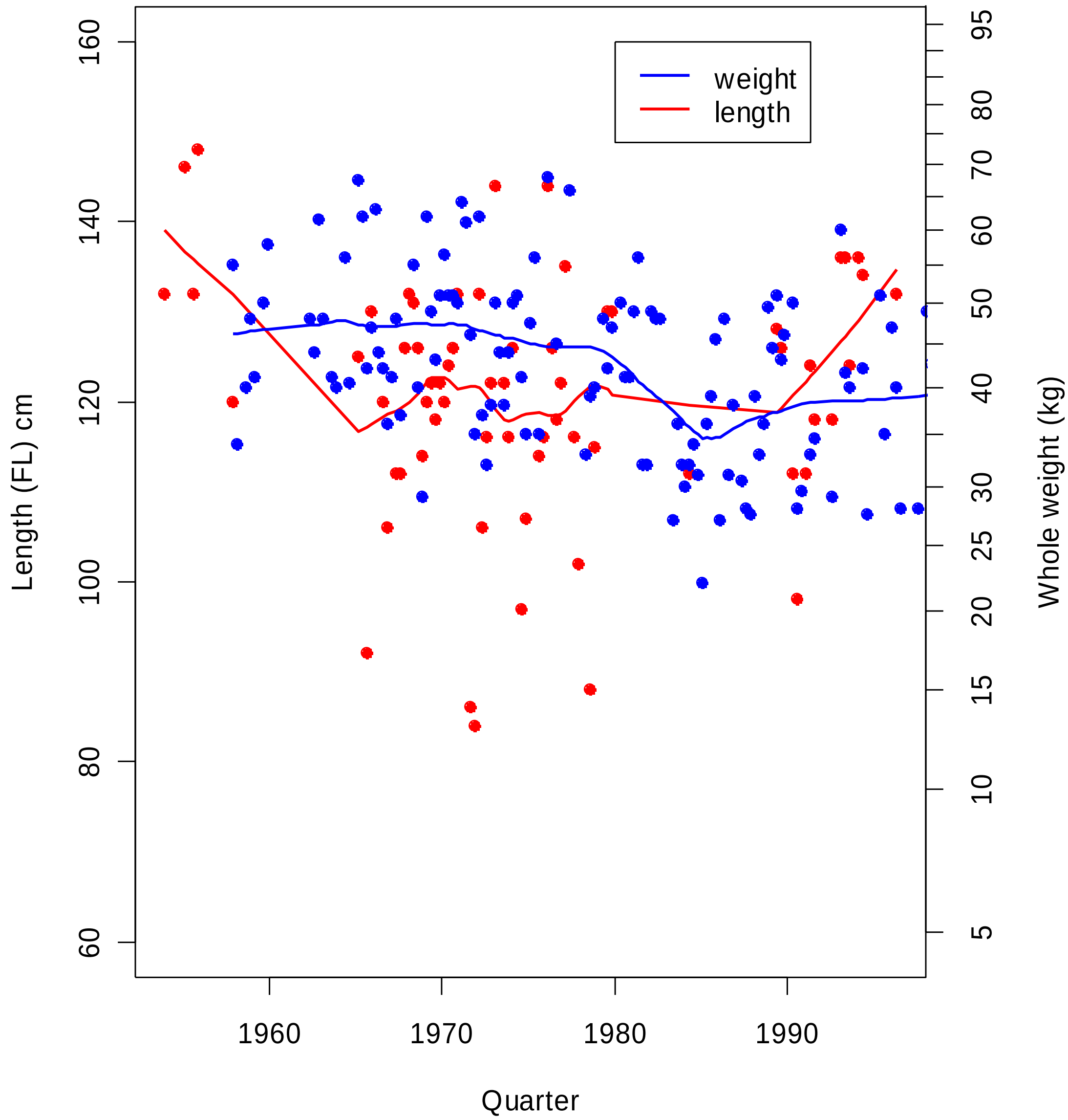

Figure 27. Median length (fork length) and weight (whole weight) of bigeye sampled from the Japanese distant-water longline fishery operating in MFCL region 5, by quarter. Only samples with a minimum of 20 fish are included. The lines represent the lowess smoothed fit to the data. For comparative purposes, the length and weight data are plotted on comparable axes (based on the length-weight relationship).

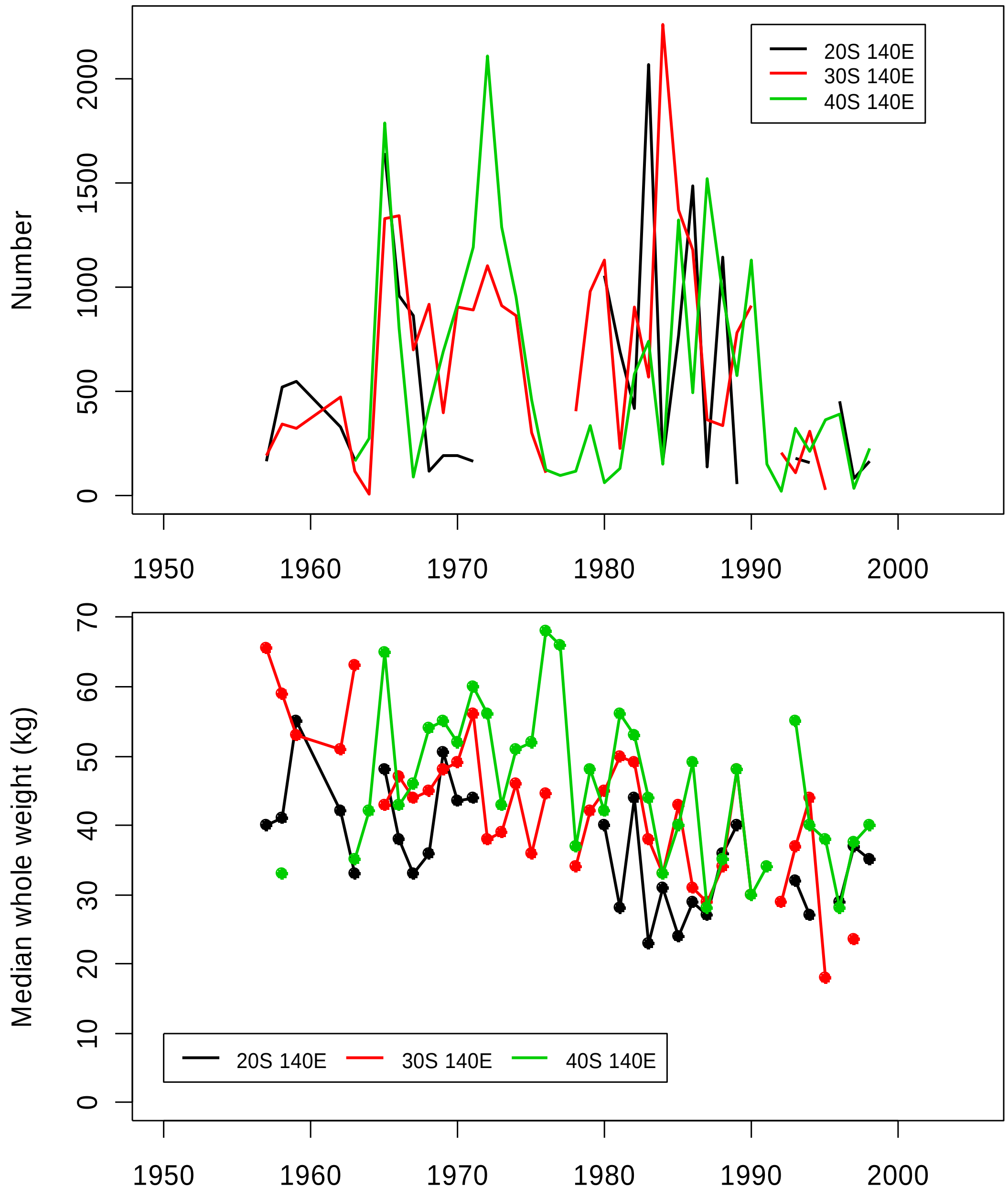

Figure 28. Annual number of bigeye weights sampled (top) and median bigeye weight (whole weight, kg) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 5. The blocks are defined by the location of the southwestern corner.

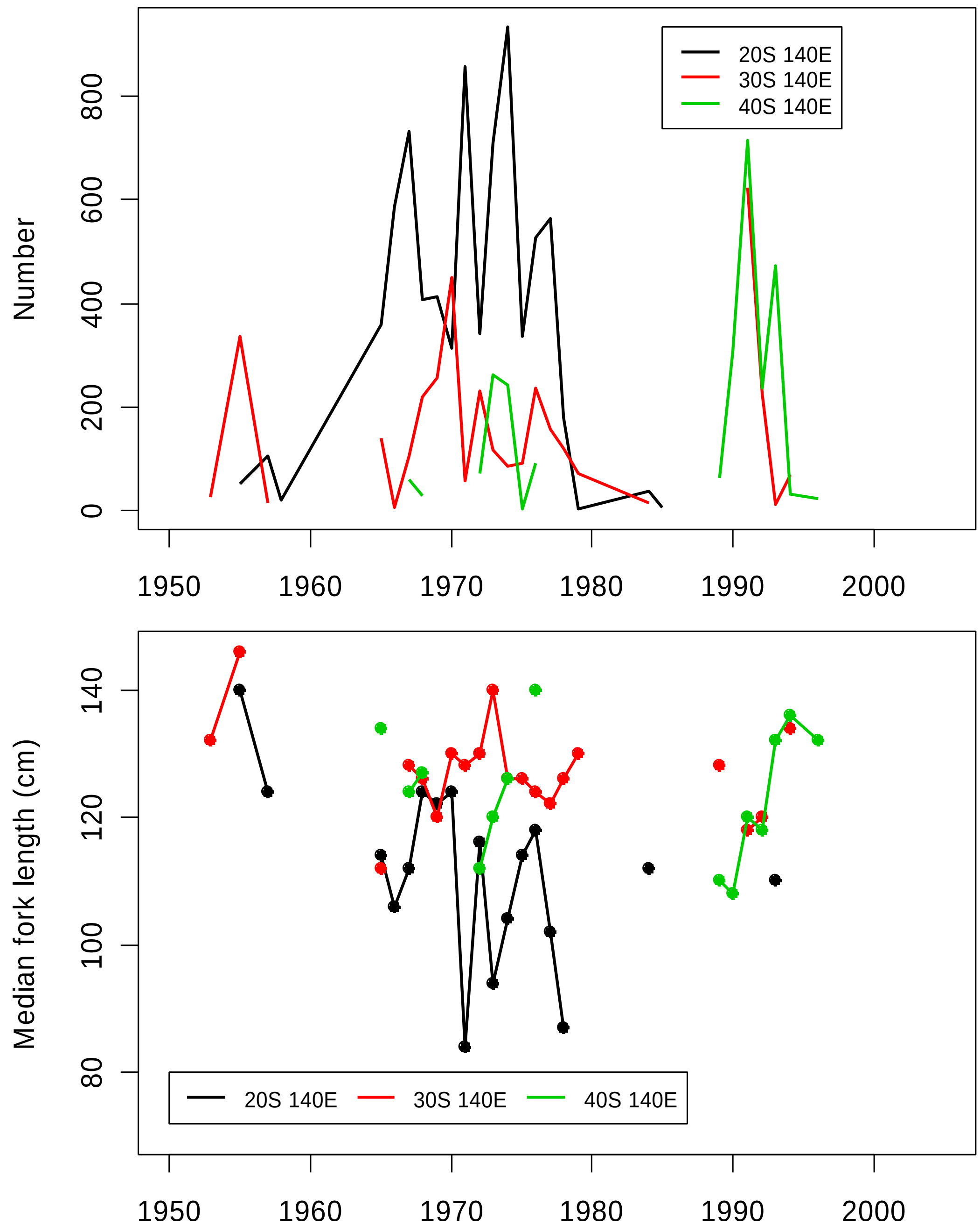

Figure 29. Annual number of bigeye lengths sampled (top) and median bigeye length (fork length, cm) (bottom) from the Japanese distant-water longline catch for each of the 10 degree latitude/20 degree longitude blocks that comprise region 5. The blocks are defined by the location of the southwestern corner.

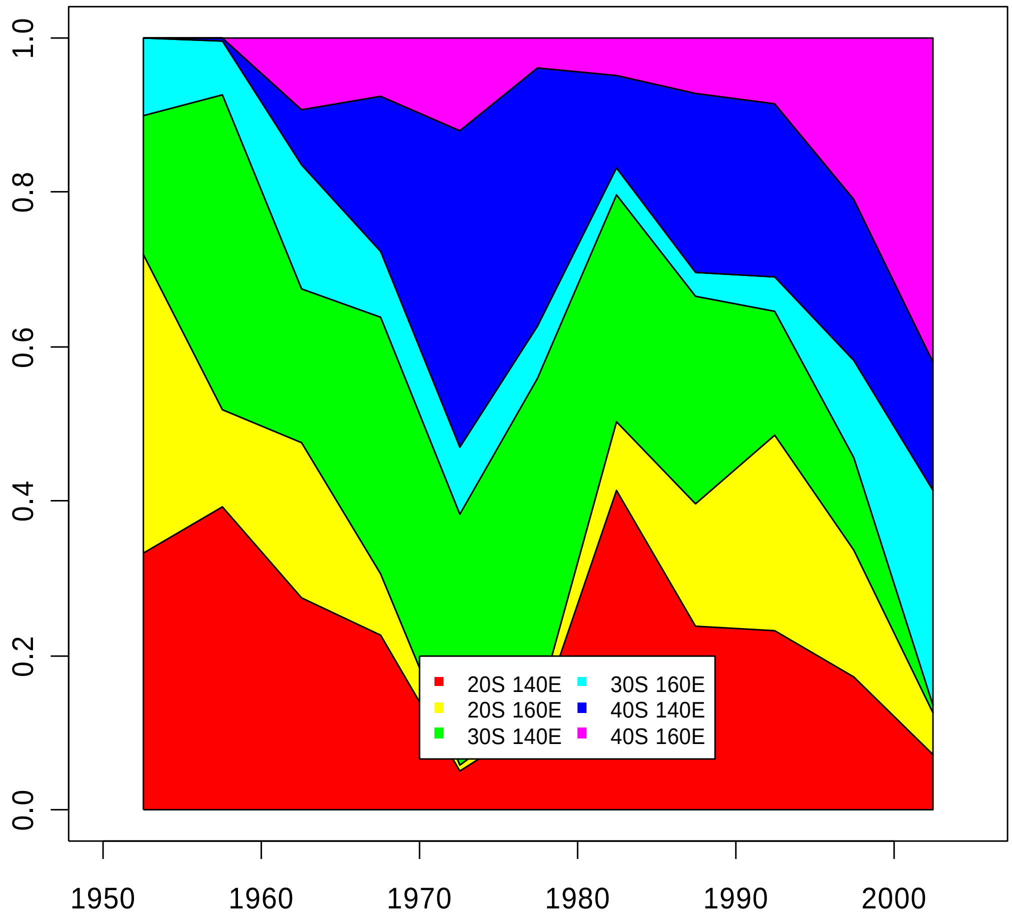

Figure 30. Proportional distribution of Japanese distant-water longline bigeye catch (number of fish) by 10 degree latitude and 20 degree longitude squares comprising MFCL region 5 by 5-year intervals.

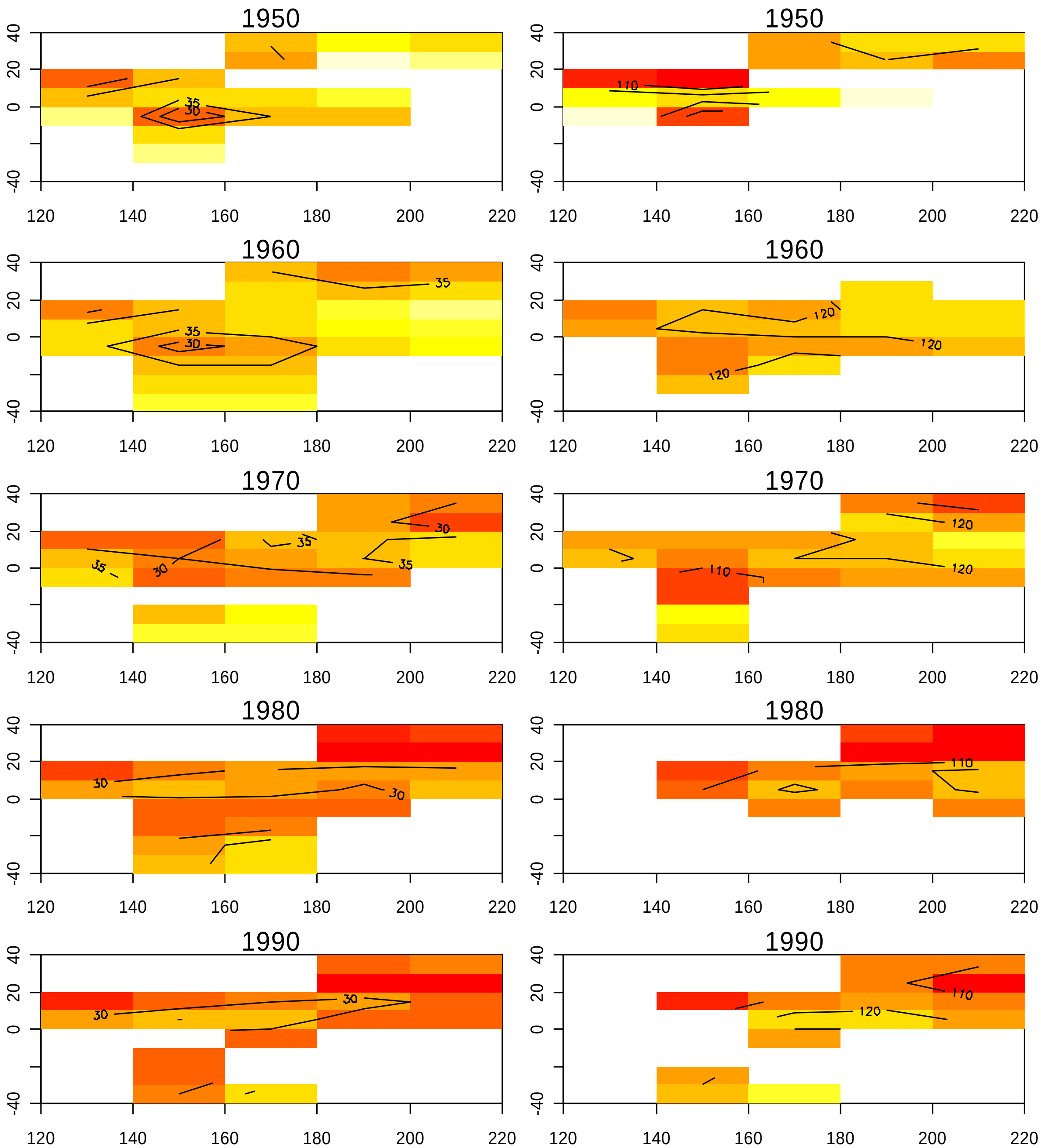

Figure 31. Spatial trends in the median weight (left) and median length (right) for longline caught bigeye in the WCPO by decade. The decades are labeled by the first year of the decade. The colour scale denotes small (red) to large fish (yellow). The lines represent contour lines of weight (30 kg, 35 kg) and length (110 cm, 120 cm).