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Information available for developing a stock assessment for New Zealand swordfish (Xiphias gladius)

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7. Executive summary

Swordfish catch in the south-west Pacific Ocean has rapidly increased since 1994 due to an expansion of the east Australian domestic longline fishery, followed by an increase in the New Zealand (NZ) domestic longline fishery that occurred shortly thereafter. Recent annual catches in each fishery are about 1 700 - 3 000 t and 500 – 1 000 t respectively. A regional stock assessment is being developed to estimate current stock status, and this report reviews the available information on NZ swordfish, and discusses its utility for an assessment model.

The main source of biological information on NZ swordfish is data collected under the Ministry of Fisheries observer programme from catches on board tuna longline vessels. Available summaries of this information include: annual length frequencies (sexes combined) since 1987, and with respect to area and sex; annual sex ratios, with area-specific estimates over all years; and, annual length-weight relationships (sexes combined) since 1988, and with respect to area and sex. Catch length composition is highly variable between years, and there is no consistent trend in mean length. The samples appear spatially representative within each of the two areas into which the fishery has been stratified (north and south). However, the temporal distribution of observer samples appears not to be representative of the fishery, rather reflecting the disproportionately high coverage of the NZ foreign charter fleet that targets southern bluefin tuna during the second quarter. The review of the information concluded that temporal stratification of the data with respect to quarter and area is required, and

therefore the disparity in the relative distribution of the sampling effort between seasons does not reduce its utility for a stock assessment.

Inherent information in a catch-at-length time series of utility for a stock assessment model includes historical mortality and recruitment variation, with the potential for estimating fishing method selectivity-at-length patterns. However, the temporal, spatial and sex-specific factors identified as affecting NZ swordfish catch-at-length must be accounted for when making inferences through fitting a population model. The review of the NZ swordfish data, the sampling methods used, and studies on age, growth and sexual dimorphism, indicate these factors affect the catch-at-length compositions available. The data must be stratified and analysed accordingly (to produce a weighted mean length frequency distribution) before it is used directly for fitting a population model. Similarly, spatial differences in the relationship between length and weight for swordfish appear dependent upon the sex ratio and the period of sample collection in relation to gonad condition. It is recommended that length-weight parameters for NZ swordfish must be estimated with respect to season and sex. Consequently, the calculation of mean individual fish weight, and hence, total annual catch in numbers of swordfish, using catch length compositions and length-weight relationships must be sex-specific and stratified temporally and spatially.

The standardised and nominal catch-per-unit-effort (CPUE) indices for swordfish for the period 1992-93 to 2003-04 were reviewed. These were calculated using catch and effort data from Tuna Longline Catch Effort Landing Returns (TLCERs), and the period was defined because it corresponds with that for which remote sensed environmental data were available. Both indices indicate an increasing trend from 1995 to 2001, with a decrease in catch rates to 2003, followed by a slight increase in 2004. A wide range of environmental and fishery operational covariates were identified as significant in determining swordfish catch rates, especially fishing location, nocturnal fishing, moon phase, and sea surface temperatures. The range of predictors identified as affecting catch rates for NZ swordfish was largely consistent with similar studies conducted elsewhere in the Pacific. Where predictors were omitted from the NZ series, such as light sticks and chlorophyll, this was due to there being a lack of information available. Light sticks have been identified as being a significant predictor in the Australian, Hawaiian, and NZ swordfish fisheries.

It is highly unlikely that the sharply increasing trend in catch rates through the period 1993 to 1998 accurately indicates relative abundance. For this part of the time series to be of utility in a stock assessment, it is suggested that a process defining a trend in catchability must be formulated and estimated. The utility of the early part of the NZ time series may be contingent upon a characterisation of the historical use of light sticks in the NZ tuna fishery, and a predictive relationship being estimated. It is recommended that information from the observer programme be used for this characterisation. This may assist in describing a likely increasing trend in catchability from 1993-98 that accounts for the increase in targeting, and the use of light sticks.

Both nominal and standardised CPUE indices were strongly seasonal. It is recommended that the quarterly CPUE indices in the NZ fishery be contrasted with east Australian swordfish CPUE in the previous and following seasons to investigate evidence of a reciprocal relationship in high and low CPUE. This is of potentially high utility for a regional stock assessment model in that seasonality in catch rates may be indicative of annual cycles in fish abundance caused by movements between NZ waters and, most likely, the tropics or Australia.

Other recommendations arising from the review of CPUE included investigating NZ catch rates on a fine resolution spatial scale to resolve the effect of localised fishing effort on the general decline in catch rates since 2000; deriving standardised indices for the Japanese longline fishery pre-1992 for describing long term trends in swordfish abundance; and determining the causes of the large difference in the nominal catch rate of swordfish evident between the Australian and NZ fisheries.

Given the conclusions of a simulation study of the performance of a north Pacific swordfish stock assessment model, the large sample size of sex-specific length frequency data collated in this project is likely to be of high utility for a south-west Pacific swordfish stock assessment. Combined with the sex ratio time series, the results of separate studies on sex-specific growth, natural mortality, and maturity-at-age, this will facilitate the development of a sex-specific and age-structured population model for swordfish. This model structure is necessary to take account of structural uncertainties induced by the sexually dimorphic growth of swordfish. In the absence of extensive tagging information, movement processes may be inferred from temporal-spatial patterns in swordfish CPUE, catch length frequency, and sex ratios. Within the annual cycle of a model, seasonal variation in length frequency and catch rates may indicate length- or sex-specific movement within the region.

The information collated from this project has immediate utility for developing a simulation operating model with which to evaluate alternative stock assessment models for the south-west Pacific region. A separate Ministry of Fisheries research project (SWO2004/01) will contribute to the development of this model and provide a sex-specific and age-structured estimator.

8. Objectives

OVERALL OBJECTIVE:

To develop a stock assessment for swordfish *(Xiphias gladius)*.

SPECIFIC OBJECTIVE 4:

> To develop a stock assessment, including estimating biomass and sustainable yields for swordfish in the New Zealand EEZ.

The original intention of this specific objective was to develop a population model making use of data available, both within NZ, and from the south-west Pacific region. An assessment framework was proposed using model estimates of the NZ component of the regional surplus production to define the annual yield for the NZ EEZ. The proposed approach recognised the limitations of regional stock assessment estimators, and encompassed a full and complete estimator model evaluation using an operating model such as that developed for management strategy evaluations (MSE) developed by Campbell & Dowling (2003).

Following a review of the project's scope, a separate project was established having this specific objective to undertake the full range of tasks required for a swordfish stock assessment (project SWO2004/01). Consequently, objective 4 of SWO2003/01 was reduced in its scope, and a suggested re-wording of the specific objective follows:

> To collate and review available information on swordfish from NZ for developing a stock assessment model

9. Methods

See attached report.

10. Results

See attached report.

11. Discussion and Conclusions

See attached report.

12. Publications

Nil.

13. Data Storage

Tuna longline observer data are stored on the Empress *l_line* database, maintained by NIWA.

Tuna longline catch and effort data are stored in the Ministry of Fisheries *tuna* database, maintained by NIWA.

1. Introduction

Swordfish is considered a highly migratory species and is found throughout the Pacific Ocean (i.e. appears in longline catches) from 50° N to 50 ° S in the western Pacific Ocean and 45° N to 35° S in the eastern Pacific Ocean. As such the availability and abundance of swordfish in New Zealand (NZ) may be subject to the dynamics of a large stock of which the NZ waters are a relatively small part.

Data from fisheries landing swordfish were reviewed by Ward & Elscot (2000) and summarised by Murray & Griggs (2005) in respect of the south-west Pacific Ocean, that included the NZ domestic longline fisheries. Swordfish are caught mainly as a bycatch to the tuna fisheries in Chile (longline, driftnet, formerly harpoon), Japan (longline, driftnet and harpoon), Hawaii (longline), and off the east coast of Australia (longline). Catches thoughout the Pacific Ocean have been increasing since far seas longline fisheries commenced in the 1950's with the recent average catch being over 26 000 t, with 31 617 t landed in 1997. The south-west Pacific Ocean component of this Pacific-wide catch is relatively small (about 6%).

Swordfish catch in the south-west Pacific Ocean rapidly increased from 1994 due to the dramatic expansion of the Australian domestic longline fishery that directly targets swordfish (Murray & Griggs 2005).. A corresponding increase occurred in the NZ domestic longline fishery shortly after. Recent catches in each region are about 1 700 – 3 000 t and 500 – 1 000 t in the Australian and NZ longline fisheries respectively. This rapid increase in catches has prompted the collation of available data for developing a stock assessment for south-west Pacific swordfish.

A preliminary stock assessment model for north Pacific swordfish has been developed using Multifan-CL (MFCL) by Kleiber & Yokawa (2002). Model estimates for important parameters were highly uncertain and sensitive to structural assumptions (ISC 2004). Also, truncation of length composition data in the smaller length classes, and the inability to distinguish between sexes were identified as weaknesses requiring further development. As such, no conclusive assessment has been developed thus far. Work is in progress to develop a model that takes account of sex-specific data (Sun et al. 2003), and further development of a simulation model to test the MFCL stock assessment model is proposed (ISC 2004).

For south Pacific Ocean swordfish, a management strategy evaluation (MSE) has been undertaken for the Australian fishery to determine a total allowable effort (TAE) allocation (Campbell & Dowling 2003). This used an operating model that best reflects the population dynamics of a south-west Pacific Ocean stock to simulate population projections to compare the performance of alternative management strategies. The operating model was not a stock assessment, but rather it emulated realistic population scenarios with which to compare possible TAEs. The approach took account of the wide distribution of swordfish in the south-west Pacific and therefore employed a regional population model.

The lack of biological and fishery observations for south-west Pacific Ocean swordfish has limited the development of an assessment (Campbell & Dowling 2003). Despite conditioning the simulation operating model on catch, effort and size data from Japanese, Australian and NZ fisheries, its dynamics were highly uncertain, requiring stock status scenarios to be assumed. Improving the amount and quality of available data with which to develop an assessment is a therefore a high priority for completing a stock assessment. In this project all available biological and catch-effort data for swordfish in NZ has been collated and summarised. This report reviews the utility of the information for input to a regional stock assessment model for south-west Pacific Ocean swordfish as specified under the revised wording of objective 4:

> To collate and review available information on swordfish from NZ for developing a stock assessment model.

This project was funded by the Ministry of Fisheries research project SWO2003/01 Objective 4.

2. Methods

Collating all information of potential utility for input to a NZ swordfish stock assessment was undertaken in three stages:

- collating the results of three other specific objectives in this project;
- identifying other information of potential utility; and
- a review of its utility for assessment.

Under specific objectives 1 and 2 of this project all historical and biological data for swordfish in NZ were sourced, collated and summarised (Griggs 2005). Historical biological data were identified and collected from all available sources and summarized (Objective 1). Length frequency data and other biological observations collected under the Ministry of Fisheries Observer Programme up to December 2004, were summarised and analysed (Objective 2).

Specific objective 3 of this project,.required swordfish catch and effort data to be collated for deriving standardised catch-per-unit-effort indices for the longline fishery (Unwin et al. 2005). Catch and effort data for the NZ tuna longline fishery over the period from 1 January 1993 to 30 September 2004 were taken from the Tuna Longline Catch Effort Return (TLCER) statistical forms provided by each fisher to MFish, and stored in the centralised database *tuna* administered by NIWA. The data were checked for errors according to established guidelines (Wei 2004).

The results from these three specific objectives were reviewed and assessed in terms of their utility for developing a stock assessment of swordfish in NZ.

Other studies of swordfish fisheries and biology carried out in NZ and elsewhere in the south-west Pacific were identified and their results reviewed for their utility in a stock assessment.

A conceptual framework for a NZ swordfish stock assessment is proposed. This takes account of the wide distribution of swordfish requiring it be assessed on a regional spatial scale. The results of a preliminary assessment of the south-west Pacific swordfish stock (Kolody et al. 2005) and other Pacific swordfish stock assessments were reviewed. In the light of this review, the utility of the NZ data is evaluated.

3. Results

Biological data

The Ministry of Fisheries observer programme is the main source of biological information for swordfish caught by the NZ longline fishery. A full description of the observations recorded on board vessels with summaries of the data is provided by Griggs (2005) and is not replicated here. Where possible, swordfish length, weight, sex, and the life status when landed is recorded, and sometimes biological samples are collected. The total number of hooks and the location of each observed set is also recorded.

The biological data summarised by Griggs (2005) are listed in Table 1. In summarising the data with respect to area, the convention used is consistent with the spatial distribution of the NZ tuna longline fleets. The domestic fleet operates mainly in the northern and eastern areas (Fisheries Management Areas, FMAs 9, 1 and 2), and the foreign charter fleet operates mainly in the south-western area with some effort in the south-eastern area (FMAs 7, 6, and3). Griggs (2005) defines the two areas for the fishery as "north", where the northern and eastern areas are combined, and "south", where the south-western and south-eastern areas are combined. This definition has been adopted for this report.

Length frequencies have been estimated annually (sexes combined), and over all years with respect to area and sex. Individual processed weights and whole weights were recorded with respect to sex. Annual catch sex ratios were calculated, with area-specific estimates over all years. Stomach contents have been identified and the proportions over the major prey types (viz. fish, squid, crustaceans, and salps), calculated over all years.

Griggs (2005) presented plots of the spatial distribution of the locations fished by the tuna longline fishery relative to those of observed sets. The 100% coverage of the NZ foreign charter fleet that operates in the south-western part of the south area ensures the catch length composition is fully represented in observer samples. The distribution of observed sets in the northern and eastern parts of the north area corresponded reasonably well with the set locations of the tuna longline fishery where swordfish were caught. Thus, the observer samples appear spatially representative of the tuna longline fishery within each of the north and south areas.

A comparison of the average annual proportion of tuna longline sets that were observed by Ministry of Fisheries observers in each quarter, with that for the tuna longline fishery from 1987 to 2004 is presented in Table 2 (data taken from Griggs 2005). Differences are evident in all the quarters indicating the temporal distribution of observer samples is not representative of the fishery. Quarters 1 and 4 receive low coverage, while quarters 2 and 3 receive relatively high coverage. This reflects the disproportionately high coverage of the NZ foreign charter fleet that targets southern bluefin tuna during the second quarter.

Catch length composition

Annual catch-at-length estimates from 1987–88 to 2004 are available from observer measurements with respect to sex and area (Table 3, taken from Griggs, 2005). Catch length composition is highly variable between years (Griggs 2005), and there is no consistent trend in mean length. Clear differences were evident between the north and south areas, that broadly reflects differences in the catch compositions of the NZ domestic and foreign charter fleets, respectively. Sex-specific catch compositions were different, with females being considerably larger (Table 3). This relates to the spatial differences observed, given that females dominate swordfish catches in the south area (Griggs 2005).

Mean weight

An estimate of the mean individual greenweight of swordfish landed in the fishery is a fundamental statistic for determining the annual total number of fish landed. For NZ statistics, reports from the licensed fish receiver returns (LFRRs) of total landed catch weight is the most reliable record of the quantity of fish caught in the fishery (e.g. 555 t in 2003-04, Sullivan et al. 2005). This greenweight tonnage is divided by the individual mean fish weight to estimate the total numbers caught in the fishery. Two approaches are available for determining mean weight. Firstly, the catch effort records from the TLCER and catch effort landing returns (CELRs) of the total numbers caught and the total estimated catch weight may be used to calculate average estimated mean weight. The recorded catch weight is not a measurement, but is instead, a visual estimate made on the judgement of fishermen. Secondly, the observer measurements of length, processed weight, or greenweight, may be used to derive an observed estimate of mean individual fish weight. This approach makes the assumption that the observer data is representative of fishery. A preliminary examination of the observer samples of processed weight and greenweight indicates a bias towards small fish particularly in the early part of the time series compared to the length frequency samples (authors unpublished data). This is likely due to practical difficulties with measuring large specimens at sea, and only data from recent years from larger vessels are likely to be representative. Therefore, the first approach has been used for the calculations presented in this report.

Length-weight relationship

Estimates of the relationship between swordfish length and weight are provided by Griggs (2005) and are presented in Table 4 and Figure 1. The estimate for the south area is clearly different from the other areas. Three factors are relevant to this finding. Firstly, observer samples from this area are collected from the longline fishery targetting southern bluefin tuna during the second quarter. This time of year is within the spawning period for swordfish, and females may have a high gonad condition index when ovaries may weigh up to 18 kg (Young & Drake 2002). Secondly, the sample is comprised of mostly females (Griggs 2005). Thirdly, as mentioned above, practical difficulties are encountered in measuring large specimens at sea by observers. It is likely the samples from the south area are not representative of the complete length range of swordfish caught. These factors may suggest the relationship between swordfish length and weight is dependent upon temporal and sex-specific factors, and observation error must be considered in deriving a relationship that is representative of NZ swordfish.

Age, growth and natural mortality

The Ministry of Fisheries research project TUN2003/01, has a specific objective 3 to determine the growth rate, age at maturity, longevity and natural mortality rate of swordfish. This represents the first study on the age and growth of NZ swordfish. A representative sample of second anal fin rays (n = 258) were collected from the fishery during 2003 and 2004 and read to determine fish age (Griggs et al. 2005). Sample readability was not consistently high, and between-reader differences occurred, showing swordfish are difficult to age. The fitted von Bertalanffy growth parameters differed between sexes, such that females attain a larger size over 6 years of age (Table 5). The estimated curves differed slightly from those estimated for east Australian swordfish (Young & Drake 2004), with the NZ L_∞ parameters being higher. The maximum age calculated was 15.3 yrs, which was considered to underestimate true longevity, and the likely maximum age was around 20 years. Using this value, an estimate of natural mortality of around 0.2 was suggested, although this is regarded as highly uncertain (Griggs et al. 2005).

Reproductive state

In 2001, as part of a collaborative study between NIWA and CSIRO, swordfish gonad samples were collected from NZ tuna longline catches for determining reproductive dynamics. These samples showed no actively spawning fish during the main spawning period (Young & Drake 2002).

As part of an age and growth study in 2003 and 2004, 373 samples were collected from NZ tuna longline catches to determine gonad condition. Few ripe or actively spawning fish were observed, making it difficult to determine length at 50% maturity. It is likely that spawning rarely occurs in northern NZ waters, and the main spawning grounds are further north in subtropical or tropical waters (Griggs et al. 2005). The estimates of 50% gonad maturity at length from eastern Australia were about 221 cm for females, and 101 cm for males (Young & Drake 2002). These lengths corresponded with ages of 9.9 years and 0.9 years respectively, based on the estimated growth curves for NZ swordfish (Griggs et al. 2005).

Movement

There is limited information available for describing the movement of swordfish in and around NZ waters. As part of a cooperative gamefish tagging programme, 113 swordfish have been tagged and released since 1987–88, with two reported as being recaptured (Holdsworth & Saul, 2005). Both recaptures exhibited long periods at liberty (8 to 11 years), with considerable growth (Griggs 2005). However, on a regional spatial scale, the net displacement from the point of release was limited (100 to 250 nm), and within the vicinity of the NZ EEZ.

Under Ministry of Fisheries research project SWO2002/01 the potential of using parasite markers to determine stock structure in NZ, and the wider SW Pacific Ocean, was evaluated (Smith et al. 2004). A pennellid copepod, a large ectoparasite, was recorded in swordfish from New Caledonia and identified as having potential utility as a parasite marker. It is readily observed externally and is most likely derived from tropical waters. Other parasites found were of limited value, requiring dissection and sample processing for identification.

Fisheries data

Catch and effort data

Specific objective three of this project was to develop standardised catch-per-unit-effort (CPUE) indices for longline-caught swordfish and contrast its performance relative to nominal CPUE. The catch-effort data used for this objective are summarised by Unwin et al. (2005). A total of 58 420 catch-effort records were extracted from the TLCER database *tuna* for the period 1992–93 to 2003–04. This period was defined because it corresponds with that for which remote sensed environmental data were available. About 12% of all the longline operations occurred in the south-western part of the south area, and nearly 100% of these operations were targeting southern bluefin tuna predominantly in the second quarter. Although swordfish are taken in this fishery, they comprise a low proportion of national landings (average 2.1% from 1993-2004), and were therefore excluded from the data used to calculate standardised CPUE. The longline fishery operating in the northern and eastern parts of the north area primarily targets bigeye tuna and accounts for on average 87% of longline operations nationally. Catch and effort data from the northern and eastern parts of the north area were combined for deriving nominal and standardised CPUE indices. The number of longline sets, number of hooks set, swordfish catch frequency, and nominal CPUE (number of swordfish caught per 1000 hooks) from 1993 to 2004 are presented in Table 6 (taken from Unwin et al. 2005). The average nominal catch rate over this period was 1.39 swordfish per 1000 hooks.

Nominal and standardised annual CPUE

The nominal and standardised annual CPUE indices from 1993 to 2004 are presented in Figure 2 (taken from Unwin et al. 2005). There is an increasing trend in standardised catch rates from 1995 to 1998, followed by a stable phase, and then a decrease to 2003, followed by a slight increase in 2004. Slight differences were evident between the nominal and standardised annual indices, but the general pattern through time was similar. A large difference was found between the average nominal and standardised quarterly indices, such that standardisation of the quarterly CPUE indices removed the large within-season variation indicated by the nominal series.

A wide range of environmental and fishery operational covariates were identified as significant in determining swordfish catch rates, including: average depth of set, depth variation within a set, the number of vessels operating within a 50 km radius of the set location during the preceding ten days, soak time, day length, the fraction of the set operation occurring at night, moon phase, mean sea surface temperature (SST), and SST anomaly. The use of light sticks has been identified as a significant factor in determining swordfish catch rates (Murray & Griggs 2005; Campbell 2005), however, this variable has been reported on TLCER forms since only 2003 (Unwin et al. 2005). It was therefore not included in the CPUE standardisation.

Catch history

A summary of NZ swordfish catch (t) by fishing fleet as reported from TLCERs and LFRRs is presented in Table 7 (taken, and updated, from Sullivan et al. 2005). Annual catches of the NZ domestic fleet increased rapidly from 1993 and peaked at over 1 000 t in the 2000-01 fishing year, but has since declined to 555 t in 2003-04. There is a consistent discrepancy between the reported estimated catch from TLCER/CELR data and the total landed catch from LFRRs (Table 7). However, the reported catch in 2003–04 is more similar to the total landed catch as reported by fish processors than in previous years.

A catch history of the total annual number of swordfish caught in NZ waters from 1952 to 2004 (Figure 3) has been collated for input to a stock assessment model for the south-west Pacific region (Kolody et al. 2005). To address the discrepancy between the total catch of swordfish reported on catch effort returns by fishermen, and that reported on LFRRs, annual total catch frequency was calculated using the LFRR landed weight divided by an estimate of the annual mean individual fish weight. As mentioned above, information from the TLCER/CELR reports of the total frequency caught and the estimated catch weight (taking account of processed state), was used to estimate annual mean weight.

Environmental data

A wide range of oceanographic variables was collated for deriving standardised indices of swordfish CPUE in the NZ tuna longline fishery. These were remotely sensed from NZ waters (Uddstrom & Oien 1999). Sea surface temperature variables included indicators of frontal strength, ocean climatology and anomalies, and temporal-spatial oceanographic conditions as described using empirical orthogonal functions (Uddstrom et al. in review). A similar range of these variables was also collated for sea surface chlorophyll. The spatial resolution was to within 1 km and calculated using five-day temporal composites.

Discussion

The available data from the NZ swordfish fishery that have been collated under objectives 1, 2, and 3 of this project, and from other research projects, is discussed in terms of its utility for developing a population model for assessing the NZ swordfish stock in the following review.

Biological data

Length frequency

The time series of length and weight frequencies collected from the observer programme is substantive information of high potential utility for a south-west Pacific swordfish stock assessment. A fundamental requirement is that the samples are representative of the fishery. This appears reasonable on the spatial scale of the north and south areas, however, the temporal distribution of sampling is not consistent with the proportion of commercial catches in each quarter. Observer coverage of the NZ foreign charter fleet that targets southern bluefin tuna during the second quarter is disproportionately high relative to the other quarters and the domestic fishery. Therefore, it is recommended that the length frequency data be stratified with respect to fleet, quarter and area for the catch length compositions to be representative of each stratum. An estimate of the NZ fishery may be derived from a mean length composition, weighted by the estimated total catch (in numbers) from each fishery stratum. An estimate of the precision of the weighted mean would take account of the sample size in each stratum, which may be low for the north area in some quarters.

Griggs et al. (2005) identified sexual dimorphism in NZ swordfish, with females attaining a larger mean length than males. Temporal differences in the sex ratio of swordfish will most likely affect catch length compositions. To take account of these factors, it is recommended that sex-specific estimates of swordfish catch-at-length be calculated at a temporal scale consistent with the regional stock assessment model. This information is of high utility for a stock assessment as sexual dimorphism has been identified as a large source of structural uncertainty in swordfish stock assessment models.

Campbell & Hobday (2003) described serial depletion of swordfish in the east Australian fishery on the basis of a detailed spatial analysis of CPUE. Under high fishing mortality, this process may be evident in catch length compositions, and indicated by a decline in mean length through time for a specific locality, such as a seamount. The process of serial fishing will, however, maintain catch length composition over broader area and through time. To detect a serial depletion effect in catch-at-length, the time series from individual locations must be calculated. Observer catch-at-length estimates for the bigeye tuna fishery operating in the north area may be expressed in fine spatial resolution to investigate temporal patterns over the period of spatial expansion in the fishery (Unwin et al. 2005).

Catch-at-length time series may have high utility in a stock assessment model. Inherent information includes historical mortality and recruitment variation, with the potential for estimating fishing method selectivity-at-length patterns. However, temporal, spatial and sex-specific factors must be accounted for when making inferences from catch-at-length data in a population model. The review of the NZ swordfish data, the sampling methods used, and studies on age and growth, indicate these factors all affect the catch-at-length compositions available. The data must be stratified and analysed accordingly (to produce a weighted mean length frequency distribution) before they are used directly for fitting a population model. Where data is missing for a stratum, e.g. in the north area for some quarters, an assumption will be required to define a proxy length distribution for the catch taken in that stratum.

Age, growth, maturity and mortality

Estimates of age and growth, and specifically mean length-at-age, are fundamental for developing an age-structured population model. Via a relationship between length and weight, length-at-age is used for calculating mass quantities, such as absolute biomass, catch weights, and yields. As well as an estimate of natural mortality, a yield-per-recruit analysis requires this information.

The NZ sex-specific growth estimates are reasonably consistent with results from east Australian swordfish, and indicate a likely maximum age of 20 years. Natural mortality estimates are highly uncertain, with the most plausible value being 0.2. Estimates of sexual maturity at length for east Australian swordfish were used in defining maturity at age for NZ swordfish. Although uncertain, this is the best information available for specifying these fundamental biological parameters for an assessment model of NZ swordfish.

Length -weight

Observer samples of individual fish weight are of high utility for calculating population model quantities of fish mass using a relationship between individual fish length and weight. As with catch length frequencies, account must be taken of temporal, spatial or sex-specific factors affecting the relationship between length and weight. A marked difference was evident between the relationships estimated for the north and south areas. Although observation error is a likely contributing factor, this result may relate to the high sex ratio of females in that area, and the period of sample collection coinciding with high gonad condition. It is recommended that length-weight parameters for NZ swordfish be estimated with respect to season and sex.

Mean fish weight

The mean weight of fish landed is a statistic derived either from fisheries statistical returns, or fisheries observer estimates of catch-at-length and length-weight parameters. It is of immediate utility in a NZ swordfish stock assessment for converting the LFRR reported annual landing weight to the total number of fish landed. It would be preferable to calculate mean weight using observer data given that these are direct measurements of individual fish taken by trained technicians. A conclusion drawn from the above discussion regarding temporal, spatial and sex-specific factors affecting swordfish catch-at-length and the relationship between length and weight, would be that it is essential these factors be accounted for when deriving the mean weight of fish landed using observer data. It is recommended that it be derived from a mean weight frequency distribution of the fishery, weighted by the number of fish landed in each temporal-spatial and sex-specific stratum. The corresponding length-weight relationship parameters are to be used for each stratum.

Stock structure

Tagging information for swordfish within NZ is very limited. The two recaptures indicated movement within or close to the NZ EEZ over a long period. This is not of high utility to a stock assessment.

Movement on a slightly larger spatial scale has been observed for swordfish recaptures from a tagging study undertaken in Australia (Robert Campbell, CSIRO, Hobart, Tasmania, pers comm.). Although some fish tagged in east Australian waters have moved large distances (e.g. 893 nm), none were recaptured outside of the Australian EEZ with movement to NZ waters.

The residence time for swordfish in NZ waters is, therefore, not known. Despite their migratory nature, it has been hypothesised that they may remain resident in a location for long periods. Genetic studies indicate the worldwide population of swordfish is genetically structured not only between the major oceans, but also within each ocean, and that gene flow is restricted despite the absence of geographic barriers (Reeb et al. 2000, Chow et al. 1997). Examination of spatially stratified catch rates in the Australian longline fishery indicated consistent declines with respect to time and high catch rates were only maintained by extending the grounds each year (Campbell 2002). This suggests that local depletion of swordfish populations may be possible if movement between areas is gradual. Information on movement is therefore of high utility for developing a regional swordfish stock assessment model. The potential identified for using ectoparasite markers on swordfish, (Smith et al. 2004), may offer an inexpensive means for monitoring temporal patterns in the movement of swordfish between the tropics and NZ.

Fisheries data

CPUE

No absolute indices of NZ swordfish abundance are available, and therefore, a time series indices of relative abundance, such as catch per unit effort information, is an important input to an assessment model. Absolute abundance indices tend to reduce model uncertainty in estimates of population size (Davies & McKenzie, 2001). However, an informative time series of indices accurately reflecting relative change in population abundance is valuable in reducing uncertainty in model productivity estimates. Accuracy of the index is difficult to determine because the actual population biomass is usually not known. The contrast between nominal and standardised CPUE indices for swordfish in the NZ tuna longline fisheries may assist with this uncertainty by indicating the factors affecting swordfish catch rates besides stock abundance.

Standardised and nominal annual CPUE indices show steady increases from 1995 to 1998, remain stable and relatively high from 1998 to 2001, and decline from 2001 to 2003. The substantial increase by around 200% from 1995 to 1998 requires careful consideration before this time series is of utility for a stock assessment model. Murray & Griggs (2005) discussed this feature and suggested a number of fishing operational factors that most likely contributed to the increase in catch rates. These include:

increased targeting for swordfish in the domestic longline fishery; changes in operations such as the time of setting, setting on or near full moon, number of hooks set, and the increased use of light sticks. The latter was identified as the most significant factor affecting catch rates (Murray & Griggs 2005). It is therefore highly unlikely that the time series through this period is an accurate index of relative abundance. For this part of the time series to be of utility in a stock assessment, a process that produces a trend in catchability must be defined and estimated.

The CPUE decline from 2000 to 2004 in NZ is consistent with a corresponding decline observed for the east Australian swordfish fishery, where in central parts of the fishery catch rates declined from over 6 fish per 1000 hooks in 2000 to around 3 fish per 1000 hooks in 2003 (Campbell & Hobday 2003). This consistency may indicate a general trend in overall swordfish stock abundance in the south-west Pacific region, but other factors affecting CPUE must first be considered.

Unwin et al. (2005) found that the significant factors affecting NZ swordfish CPUE were year and quarter; and important predictors were location (particularly longitude); depth, and depth variation (especially areas of high bathymetric gradient, e.g. continental slope and over local seamounts); local fishing effort; night fraction; moon phase (CPUE was highest during the hours of darkness and increased around the time of the full moon); mean SST (positively correlated); and, SST anomaly (negatively correlated with CPUE). Similarly, Murray & Griggs (2005) identified the predictors moon phase, night fraction, area, and season as significant for NZ swordfish CPUE, but they found light sticks to be the most significant predictor. This predictor was excluded from the analysis by Unwin et al. (2005), because of lack of available data before 2003.

Although evident in some localities, no significant relationship between large-scale climatic predictors, localised SST or SST anomaly and swordfish CPUE was found over the wider fishery for swordfish in eastern Australia (Campbell & Hobday 2003). Rather, a fine scale spatial analysis revealed indications of serial depletion from fishing grounds around seamounts, which identified fishing location as the most important variable. Location was also found to be significant in the Hawaiian swordfish fishery (Bigelow et al. 1999), but SST, SST frontal energy, and variation in both these predictors were also important. This is consistent with the results of Unwin et al. (2005). Bigelow et al. (1999) also determined that light sticks were a highly important predictor, and this is consistent with the findings of Murray & Griggs (2005) for NZ swordfish, and Campbell (2005) for Australian swordfish. Seki et al. (2002) described a mechanism for the relationship between catch rates of Hawaiian swordfish and oceanographic structures, which links swordfish abundance to high primary productivity associated with oceanic frontal systems. Although investigated by Unwin et al. (2005), chlorophyll was not a strong predictor of swordfish CPUE in the NZ tuna longline fishery, but this investigation was limited by the short time series of available remote sensed chlorophyll data.

The results of the CPUE model for NZ swordfish are largely consistent with the findings of similar studies conducted elsewhere in the Pacific. Where predictors were omitted, such as light sticks and chlorophyll, this was due to there being a lack of information available. Light sticks have been identified as being a significant predictor in the Australian, Hawaiian, and NZ swordfish fisheries. Therefore, the utility of the NZ time series is contingent upon a characterisation of the historical use of light sticks in the NZ tuna fishery, and the predictive relationship being estimated. It is recommended that information from the observer programme be used for this characterisation. This may assist in describing a likely increasing trend in catchability from 1993-98 that accounts for the increase in targeting or the use of light sticks. If combined with anecdotal information from the fishing industry and tuna fisheries experts, a prior distribution may be defined for deriving Bayesian estimates of a catchability trend in fitting a stock assessment model to the CPUE time series. Similarly, the characterisation may also describe the trend in light stick use through the recent period in which a decline in CPUE has occurred.

Unwin et al. (2005) identified a strong seasonal (quarter) factor in both nominal and standardised CPUE. This finding is of potentially high utility for the development of a regional stock assessment model in that seasonality in catch rates may be indicative of annual cycles in fish abundance caused by movements between NZ waters and, most likely, the tropics or Australia. It is recommended that the quarterly CPUE indices in the NZ fishery be contrasted with east Australian swordfish CPUE in the previous and following seasons to investigate evidence of a reciprocal relationship in high and low CPUE. Should such a relationship exist, it may indicate east-west seasonal migrations.

In reviewing the NZ CPUE information, three items of additional work are recommended for improving its utility for a stock assessment. The first item relates to the period of stable swordfish catch rates from 1998 to 2001, followed by the decline to 2004. Apparent evidence of spatio-temporal depletion of swordfish in the east Australian fishery prompts an investigation of catch rates on a fine resolution spatial scale of the NZ domestic fishery operating in the north areas. This may resolve the effect of localised fishing effort on the general decline in catch rates through this period. Secondly, a Japanese longline fishery for swordfish operated in NZ waters before 1992 (Table 7), and catch and effort observations are available since 1960 (Murray & Griggs 2005). Standardised indices for this period may be of utility in describing the long term trend in swordfish abundance. Thirdly, a large difference in the nominal catch rate of swordfish is evident between the Australian and NZ fisheries. For the adjacent fishing grounds of the east Australian fishery and in the north area of NZ EEZ, Australian catch rates are higher by a factor of up to 3.0. Distinct differences in the fishing characteristics of the two fleets should be identified, for example, it may be possible a substantial fraction of the NZ effort is targetting bigeye tuna (Murray & Griggs 2005) such that fishing gear deployment is not optimal for swordfish.

Catch history

In preparing catch and effort data for the CPUE general linear model (GLM) analysis, a history of the total annual number of swordfish caught in NZ waters and total effort in the tuna longline fishery has been collated for the period 1993 to 2004. This information is of direct utility for developing a south west Pacific population model swordfish, as it is used for defining the total annual removals of swordfish from NZ waters and the actual fishing effort expended. This data will be appended to a long-term time series available since 1952 that has previously been collated as part of a separate project SWO2004/01 to undertake a regional south west Pacific swordfish stock assessment.

Utility for an assessment model

To gauge the utility of the information collated above relative to that used in existing Pacific swordfish stock assessments, a brief review of these assessments follows.

A preliminary assessment for north Pacific Ocean swordfish is available (Kleiber & Yokawa 2002) and a framework has been prepared for developing an assessment that accounts for structural uncertainties, particularly in relation to sexual dimorphism in swordfish (Sun et al. 2003). A sex-specific age-structured assessment method for North Pacific swordfish was subsequently evaluated by simulation to identify the main sources of uncertainty (Wang et al. 2005). Process error in the relationship between CPUE and abundance was found to have the greatest impact on model performance, in terms of both bias and precision. This effect could be offset through increasing the sample size of length-frequency information, particularly where there are several sources of uncertainty in fitting the assessment model.

The results of Wang et al. (2005) highlight the importance of understanding the relationship between the index of abundance and absolute abundance. Therefore, estimating predictive relationships between CPUE and fishing operational variables (e.g. light stick use) and environmental covariates are of high utility for swordfish stock assessments. Environmental data collated during this project may be used for defining habitat preferences for swordfish. This is of utility for applying the more general habitat-based statistical (HBS) method for standardising CPUE. It uses an integrated approach for fitting the parameters of the HBS while fitting a population dynamics model to auxiliary data (Hinton & Maunder 2003, Maunder & Langely 2004). However, this method is conditional upon the functional form of the habitat preference relationship being known.

Given the conclusions of Wang et al. (2005), the large sample size of sex-specific length frequency data collated in this project is likely to be of high utility for a swordfish stock assessment. Combined with the sex ratio time series, sex-specific growth, and maturity-at-age estimates, this will facilitate the development of a sex-specific and age-structured population model for swordfish. Fundamental structural assumptions such as minimum and maximum age, and aggregate age class (plus group) may be defined using this information. It is not uncommon for swordfish of less than 1 m fork length to be caught in the NZ tuna longline fishery, and the first mode is typically around 1.2 m. Therefore, in fitting the assessment model to the length frequency time series, it may be possible to infer year class strength variability. This will be dependent upon the inter-annual consistency in the length frequencies and the fishing method-specific selection function estimated.

In developing an operating model for south-west Pacific Ocean swordfish, it was conditioned on catch, effort and size composition data from the Japanese, Australian and NZ longline fisheries (Campbell and Dowling 2003). The results were found to be sensitive to the assumed values for natural mortality, recruitment, and movement, and stock status was unable to be estimated. The model population dynamics were highly uncertain and this was attributed to the lack of information available with which to estimate model parameters.

The immediate utility of the information collated from this project is for developing a simulation operating model with which to evaluate alternative stock assessment models for the south-west Pacific region (Kolody et al. 2005). A separate Ministry of Fisheries research project (SWO2004/01) will contribute to the development of this model and provide a CASAL candidate estimator (Bull et al. 2005). The operating model makes the assumption that there is a discrete south-west Pacific stock. This seems reasonable given that genetic studies indicate the worldwide population of swordfish is genetically structured not only between the major oceans, but also within each ocean, and that gene flow is restricted despite the absence of geographic barriers (Chow et al. 1997, Reeb et al. 2000). Within this region, the model is spatially disaggregated with the NZ waters being separated into the north and south areas, which broadly correspond with the areas defined by Griggs (2005) for stratifying observer data. Candidate assessment models will most likely replicate the spatial stratification of the operating model. Therefore, this offers a framework for assessing swordfish in NZ waters, i.e. that component of the annual dynamics and abundance existing within the spatial strata consistent with the NZ EEZ.

This assessment framework will most likely be sensitive to uncertainty in estimates of movement, and the assumptions made relating to movement parameters, e.g. sex- or length-specific factors. Preliminary results from a Multifan-CL estimator have exhibited this as a major source of uncertainty (Kolody et al. 2005). Therefore, movement information is identified as being a high priority for developing a regional stock assessment for swordfish in the south-west Pacific, and for NZ as a component of that assessment.

Unfortunately, the movement information collated in this project is limited and is of low utility for developing a south-west Pacific regional swordfish stock assessment model. Although offering promise for collecting information in the future on swordfish movement, no information is currently available from an examination of external parasite markers on swordfish. For direct information on movement, it is recommended that efforts be made to undertake studies of swordfish movement within the south-west Pacific region in the near future using, for example, electronic satellite tags that record fish location, or via parasite markers.

In the absence of this information, movement must be inferred from temporal-spatial patterns in swordfish CPUE, catch length frequency, and sex ratios. Within the annual cycle of a model, seasonal variation in length frequency may indicate length-specific movement between areas. This further highlights the importance of length frequency information for a swordfish stock assessment. A separate Ministry of Fisheries research project currently in progress (TUN2005/02) aims to establish the routine collection of size composition data in NZ commercial swordfish catches from port samples. Combined with observer information on sex-specific catch length frequencies, this will establish a time series of information of potentially high utility for assessing swordfish in the south-west Pacific region.

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Table 1: Summary of biological information collected for swordfish by observers on board tuna longline vessels in the NZ EEZ from 1987 to 2004.

Observation type	Sample size	Collection period	Status of information
Length frequency	5 300	1987 to 2004	Annual summaries, sex- and area-specific estimates
Length-weight	3 713	1988 to 1994 and 1997 to 2004	Annual, sex- and area-specific estimates
Sex ratio	3 880	1988 to 2004	Annual, area specific estimates
Gonad condition	373	2003 to 2004	Annual summaries
Anal fin ray (age)	258	2003 to 2004	Samples have been aged, natural mortality estimated
Stomach contents	2 463	1994 to 2004	Major taxa identified
Capture life status	4 057	1992 to 2004	Annual summaries, sex- and area-specific estimates

Table 2: Average annual proportion of tuna longline sets that were observed by Ministry of Fisheries observers in each quarter, and that for the tuna longline fishery (determined from commercial fishing returns) from 1987 to 2004. Data is taken from Griggs (2005).

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Fishery	0.209	0.503	0.222	0.066
Observed	0.094	0.754	0.138	0.014

Table 3: Summary of length frequency parameters for swordfish caught by longline in the NZ EEZ, categorised by year, region of capture and sex. n = sample size. Source: Griggs (2005).

Year	**n**	**minimum**	**maximum**	**average**	**std. dev.**
1987-88	109	82	256	174.3	36.4
1989	115	99	247	171.5	31.8
1990	444	93	300	170.3	36.2
1991	258	110	290	177.9	37.1
1992	243	76	280	166.8	34.9
1993	203	98	289	188.1	38.2
1994	82	107	279	177.4	39.1
1995-96	65	105	285	176.4	35.3
1997	433	78	278	183.4	35.2
1998	543	76	287	173.8	41.0
1999	311	82	295	203.4	43.8
2000	275	95	281	187.9	44.1
2001	705	78	295	166.8	47.6
2002	242	76	330	177.4	50.3
2003	160	68	314	192.1	54.2
2004	335	81	292	169.5	43.8

	n	**minimum**	**maximum**	**average**	**std. dev.**
Males	907	76	289	162.9	37.3
Females	2842	78	330	186.6	42.4
North	3800	68	295	166.9	37.5
South	724	131	330	231.8	24.7
North, males	848	76	289	158.3	33.5
North, females	2236	78	295	174.3	37.6
South, males	59	173	287	229.3	25.1
South, females	606	131	330	231.8	24.8

Table 4: Estimated length-weight relationship parameters (wt = $\boldsymbol{a}$ lgth$^{\boldsymbol{b}}$, wt in kg, lgth in cm) for NZ swordfish by sex and area. n = sample size

	n	a	b
North	2 298	4.506×10^{-6}	3.21
South	537	1.151×10^{-4}	2.62
Males	562	6.524×10^{-6}	3.14
Females	1 817	3.617×10^{-6}	3.25
All	2 835	3.879×10^{-6}	3.24

Table 5: Estimated von Bertalanffy growth curve parameters for NZ swordfish by sex (taken from Griggs et al. 2005).

Sex	***n***	L_∞	**s.e.**	***k***	**s.e.**	t_0	**s.e.**
Male	73	394.4	248.5	0.044	0.047	-5.86	2.72
Female	167	434.7	105.8	0.053	0.023	-3.46	1.18
Both	252	576.6	209.7	0.033	0.018	-4.55	1.09

Table 6: Number of sets, number of hooks, total swordfish catch, and mean nominal CPUE (swordfish per 1000 hooks), by year, for longliners operating in northern and eastern areas from 1993 to 2004[1], based on TLCER returns. (Taken from Unwin et al. 2005).

Year	**Number of sets**	**Number of hooks (× 1000)**	**Number of swordfish landed**	**Mean CPUE**
1993	1 259	1 651.6	964	0.59
1994	1 446	1 237.4	975	0.78
1995	1 725	1 481.1	817	0.54
1996	1 458	1 229.3	1 277	1.07
1997	1 504	1 335.7	1 567	1.16
1998	2 503	2 478.0	3 963	1.72
1999	4 214	4 418.7	6 356	1.56
2000	5 259	5 799.3	9 175	1.62
2001	6 221	7 188.3	11 835	1.67
2002	6 673	7 875.8	10 652	1.37
2003	5 937	7 156.7	8 443	1.20
2004	3 730	4 355.3	6 850	1.60
Total	**41 929**	**46 207.3**	**62 874**	**1.39**

[1] January to September

Table 7: Reported catches (t) of *X. gladius* by fishing year (from TLCER and CELR data) for the New Zealand domestic fleet (NZ), the chartered and Japanese foreign licensed fleet (JPNFL), and from these fleets operating outside the NZ EEZ (NZ ET) from 1979/80 to 2003/04. (Taken, and updated, from Sullivan et al. 2005).

Year	JPNFL	NZ	Total	LFRR	NZ ET
1979/80	386.0		386.0		
1980/81	756.1		756.1		
1981/82	734.6		734.6		
1982/83	436.1		436.1		
1983/84	384.8		384.8		
1984/85	316.1		316.1		
1985/86	673.6		673.6		
1986/87	575.5		575.5		
1987/88	286.2		286.2		
1988/89	181.1		181.1		
1989/90	194.3		194.3		
1990/91	211.9	21.9	233.8	41.0	0.5
1991/92	194.5	33.5	228	32.0	0.6
1992/93	31.1	46.8	77.9	79.0	0.6
1993/94		88.2	88.2	102.0	2.6
1994/95		91.4	91.4	102.0	0.8
1995/96		148.6	148.6	187.0	2.5
1996/97		223.3	223.3	283.0	0.2
1997/98		379.7	379.7	534.0	2.8
1998/99		679.1	679.1	965.0	2.9
1999/00		778.0	778.0	976.0	4.6
2000/01		901.4	901.4	1022.0	25.4
2001/02		709.0	709.0	956.0	0.0
2002/03		583.3	583.3	670.0	0.5
2003/04		503.3	503.3	555.0	0.5

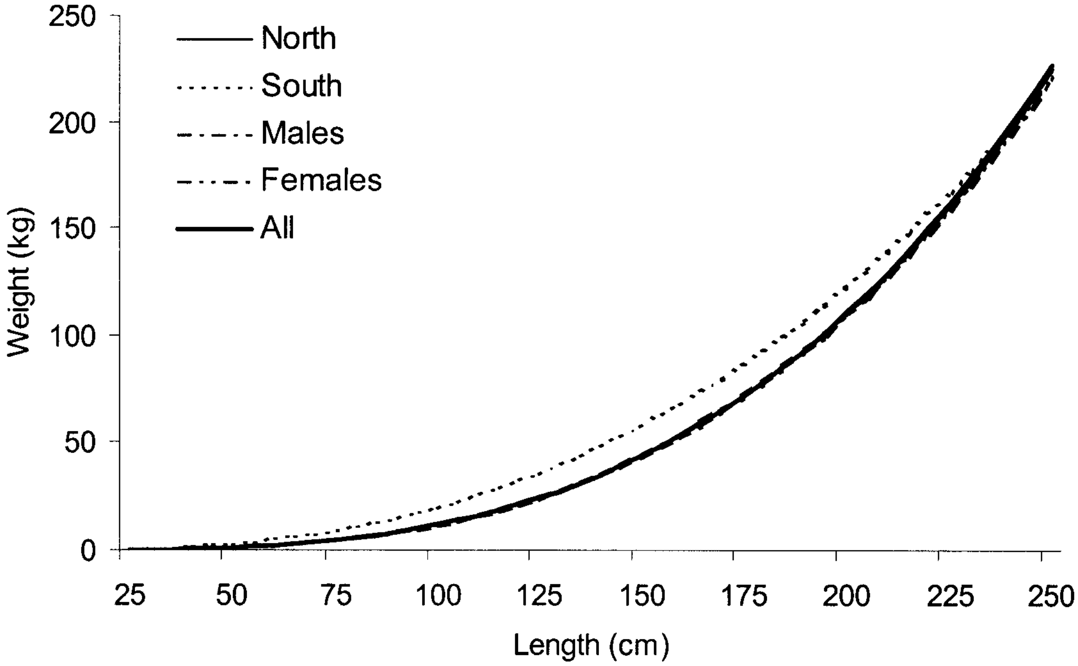

Figure 1: Estimated length-weight relationships for NZ swordfish with respect to sex and area, and combined.

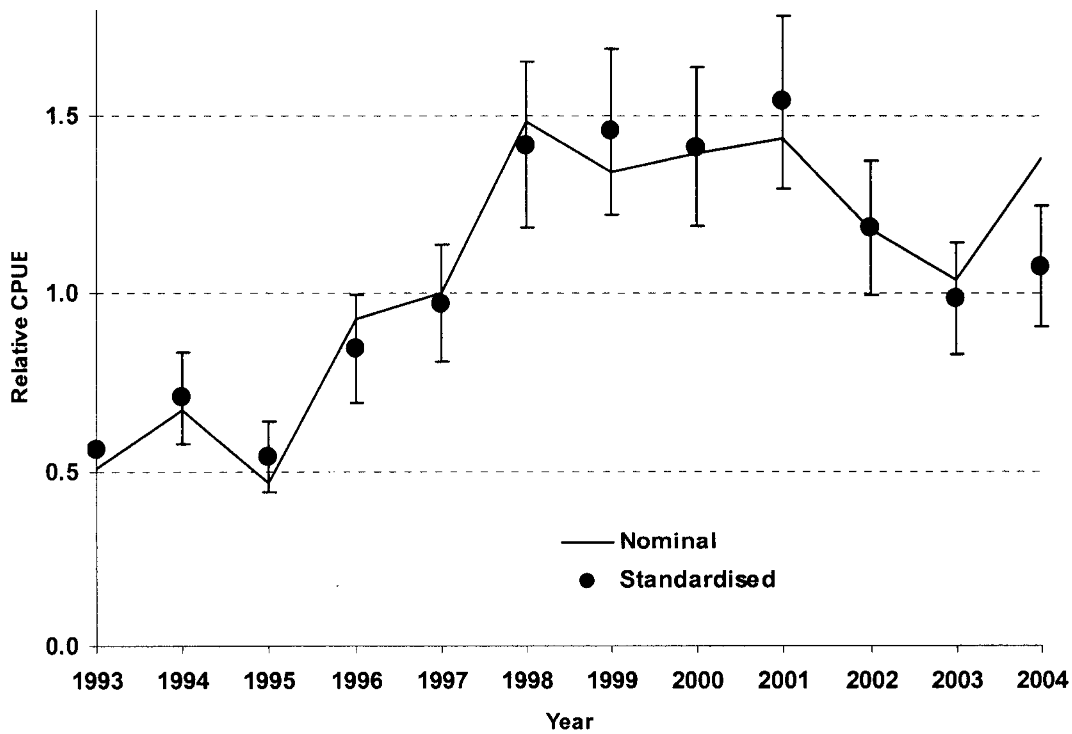

Figure 2: Nominal and standardised annual CPUE indices (normalised about the geometric mean for each time series) for the longline fishery, 1993-2004. Vertical bars indicate two standard errors. (Taken from Unwin et al. 2005)

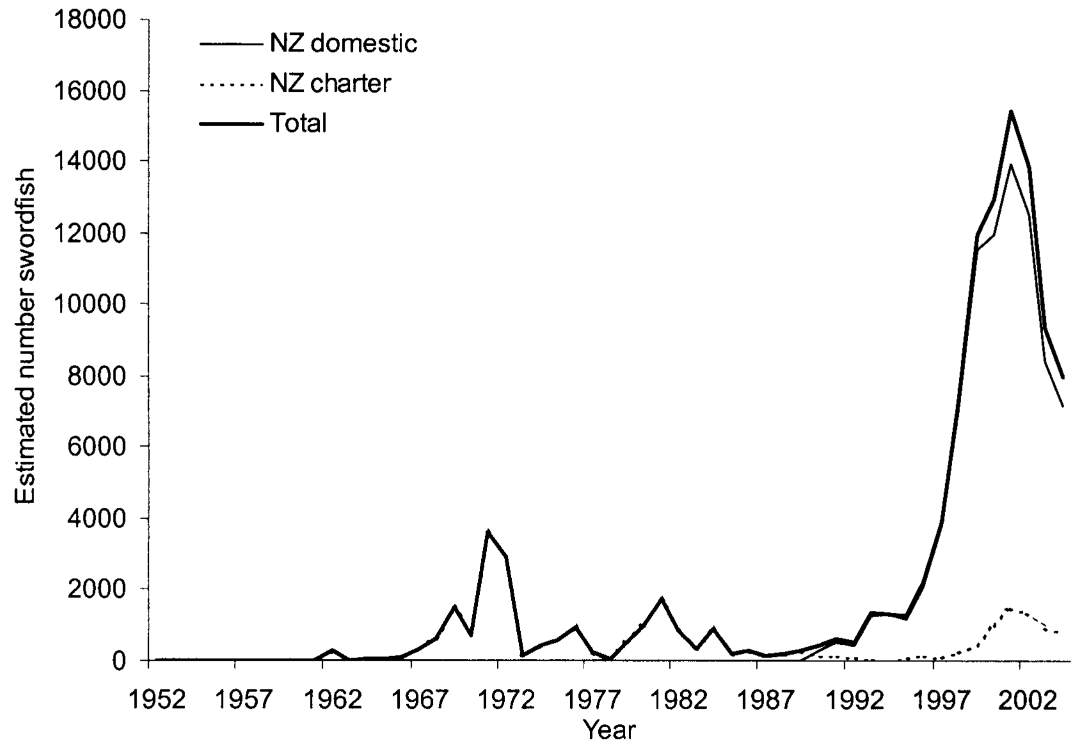

Figure 3: Annual total swordfish catch frequency in the NZ EEZ by the domestic and foreign licensed or charter fisheries from 1952 to 2004.