Sequential changes in swordfish catch rates off eastern Australia and possible implications for the spatial distribution of the local swordfish population

Robert Campbell

CSIRO Division of Marine Research
Hobart, Australia
Sequential changes in swordfish catch rates off eastern Australia and possible implications for the spatial distribution of the local swordfish population

Robert Campbell
CSIRO Division of Marine Research, Hobart, Australia

July 2002

Working Paper presented to the 15th meeting of the Standing Committee on Tunas and Billfish, July 21-26, 2002 Honolulu, Hawaii
Sequential changes in swordfish catch rates off eastern Australia and possible implications for the spatial distribution of the local swordfish population

Robert Campbell
CSIRO Marine Research, Hobart, Australia
July 2002

1. Introduction

Up until 1995 broadbill swordfish (Xiphias gladius) had remained a small, principally bycatch, component of the Australian longline fishery operating off eastern Australia, with the annual catch generally being less than 50 tonnes. However, during 1995 several vessels began targeting swordfish off southern Queensland, operating out of the port of Mooloolaba about 100 kilometers north of Brisbane (Figure 1). Good catches were obtained around several seamounts within what the Japanese traditionally referred to as the “Brisbane Grounds.” As a result of this initial success, and with increased access to the US market, between 1995 and 1996 the total retained catch of swordfish taken in the fishery increased 10-fold to around 692 tonnes. The fishery continued to expand over the next few years and by 1999 the total catch of swordfish reached 1,890t, becoming the largest catch component in the fishery for that year. During the next two years (2000 and 2001) the rapid expansion seen in the catch of swordfish since 1995 was curtailed, with the total annual catch of swordfish in the fishery averaging around 1,950t.

The increase in the catch of swordfish was not solely due to an increased targeting of this species, but also coincided with a large expansion in the total effort in the fishery. Total annual effort increased from around 4 million hooks in 1994 to over 11 million hooks in 1999 (Table 1). The spatial extent of the fishery also increased, with the number of one-degree squares of latitude and longitude fished each year increasing from less than 130 before 1995 to around 250 during 2000. In line with the increased focus on swordfish, most of this expansion occurred on the “Brisbane Grounds” (defined here as the region bounded by 24-34°S, 152-164°E, cf. Figure 1) where the number of squares fished increased three-fold (from 43 to 125) between 1994 and 2000.

Although the "Brisbane Grounds" now account for around half of the entire spatial extent of the fishery, a greater share of the total annual catch and effort is concentrated in this region. For example, since 1999 this region has accounted for around two-thirds of the total annual effort in the entire fishery and over 80% of the total swordfish catch (Table 2.)

2. Trends in Swordfish CPUE

The total Australian longline effort deployed each year on the "Brisbane Grounds" is shown in Figure 2, together with the associated nominal catch rate of swordfish. The increase in effort between 1995 and 1997, associated with the increased targeting of swordfish, coincided with a large increase in catch rates. On average, catch rates increased from below 1 fish per 1000 hooks to over 7 fish per 1000 hooks. Between 1997 and 1999 nominal annual effort doubled to around 6.5 million hooks, but during this same period nominal swordfish catch rates decreased to around 5 fish per 1000 hooks. While effort remained relatively constant over the next two-years, catch
rates continued to decline, reaching around 3.5 fish per 1000 hooks during 2001 (around half the high value achieved in 1997).

As already stated, the increase in domestic fishing operations on the Brisbane Grounds also coincided with an expansion of the area fished. This expansion has generally been in an offshore direction, with new and larger boats travelling further per trip and spending more days away from port. However, as the fishery has expanded into new areas each year, the areas fished in previous years have continued to be fished. As such, the fishery now consists of a mosaic of areas that have been fished between one and seven years since 1995.

The spatial extent of the fishery each year between 1995 and 2000 together with the associated catch rates in each 1-degree square of latitude and longitude is shown in Figure 3. Examination of these maps indicates that high catch rates were obtained in the inshore region during the initial years of the fishery but these catch rates have declined over time. On the other hand, as the fishery has expanded offshore each year, the catch rates obtained in the new areas fished are seen to be similar to the catch rates initially obtained in the inshore regions. In effect, the fleet has been able to maintain catch rates within the offshore sector of the fishery by continuing to expand further offshore each year.

Figure 4 shows the average effort levels within those 1-degree areas squares on the "Brisbane Grounds", which for each indicated year, have been fished for \( n \) of the years between 1995 and 2001. For example, in the figure for 1996 the average effort associated with those squares fished for the first time that year is given by the \( \text{Years_Fished} = n = 1 \) column, while those squares which have been fished for 2 years are associated with the \( n = 2 \) column. There are no columns associated with \( n > 2 \) for this year as there are no squares which have been fished three or more years since 1995. For each year there is a positive relationship indicating a general increase in average effort the greater the number of years an area has been fished. Furthermore, if one follows the sequence of squares fished the greatest number of years (ie. \( n = 2 \) for 1996, \( n = 3 \) for 1997, etc), then one also sees that there has been a general increase in the annual effort in the associated areas over time.

In Figure 5, the average nominal swordfish catch rates associated with the areas described in Figure 4 are also shown. For example, in the figure for 1999, the height of the column associated with \( n = 5 \) gives the average catch rate (3.1 fish/1000 hooks) across those 1-degree squares fished in all five years since 1995. In general, catch rates show a steady decline the longer an area has been fished. For example, during 1999, the average catch rates across areas first fished (\( n = 1 \)) is around 10.9 fish per 1000 hooks (fpth), decreasing to 8.4 fpth for \( n = 2 \) years, 7.5 fpth for \( n = 3 \) years, 5.7 fpth for \( n = 4 \) years and 3.1 fpth for \( n = 5 \) years. Furthermore, apart from the first two years when the fishery was developing, the average catch rates across areas first fished have been around 11 fish/1000 hooks. On the other hand, the catch rates in those areas which had been fished for 4 or 5 years have generally averaged around half this value.

The above observations indicate a strong relationship between the catch rates in an area and both the present and historical levels of fishing effort in that area. In particular, there appears to be a strong inverse relationship between catch rates and the number of years any area has been fished. The observations also indicate that during each year relatively high catch rates have been maintained on the periphery of the fishery as it continues to expand further offshore. However, catch rates in the inshore regions fished in previous years tend to show a relatively consistent pattern of decline over time. If this pattern of 'localised decline' continues to be observed in future years there may be negative consequences to the viability of the longline fishery and possibly for the swordfish populations in this region.
3. Explanatory Hypotheses

Much of the initial effort directed at swordfish was around the inshore Tasmanid seamounts within the East Australia Current (EAC), and in more recent years effort has also been targeted around the seamounts further offshore. In line with the general observations reported above anecdotal reports indicate that the sub-populations of swordfish around these features have decreased over time.

Given this pattern of effort, one hypothesis that may explain the decreases observed in catch rates is that there is an ongoing sequential depletion of localised sub-populations of swordfish around seamounts. For example, if there is an affinity of sub-populations of swordfish to particular locations (ie. seamounts), and if these sub-populations have a slow replenishment dynamics, then these sub-populations remain vulnerable to fishing. While swordfish are considered to be highly migratory, it remains possible that sub-populations may be resident around the seamounts off eastern Australia. Furthermore, while individuals within these sub-populations may move large distances, it is also possible that many of these fish return to the same seamount. In response to fishing, the size of such sub-populations would be reduced over time, and this would be reflected in declining catch rates. This is analogous to the resource being mined in the sense that the average ‘grade’ of the resource in an area decreases with continued effort, ie. the high grade areas are fished out leaving a lower residual density.

If swordfish display a relatively high degree of affinity to features such as seamounts, then as the sub-populations on these features are fished down, it would appear that they are not readily replenished by swordfish that associate with other features in the region. This implies a high 'stickiness' or viscosity of the swordfish resource, ie. the movement of fish away from a resident area into an area heavily fished is relatively slow. Indeed, one explanation of the fish down effect observed is that the rate of movement of fish into the inshore areas of the fishery is not rapid enough to allow the population density to rebuild, ie. the rate at which fish are being removed is larger than the replenishment rate, with the consequence that the size of the resource (and consequently catch rates) in the these fishing area has decreased over time. The build up of excessive effort in these areas would help exacerbate this effect. An interesting experiment would be to close part of the fishery where catch rates have declined significantly (ie. an area fished for many years) to see if after a period with no fishing the population can rebuild. However, the monitoring and enforcement of such a closure could be problematic.

The concepts of local residency and high viscosity for swordfish is contrary to the usual manner in which we think about the movement dynamics of 'a highly migratory species.' If one considers a swimming pool which is full of 'highly migratory' fish, then one would normally argue that even if one removed fish from only one spot that the density of fish throughout the pool would remain relatively homogeneous. This is because the rapid movement of fish throughout the pool would statistically re-distribute the fish throughout the pool so that, on average, the resulting density remained relatively homogeneous. The observations described above, however, would seem to indicate that this is not occurring for the swordfish population off eastern Australia.

A variation on the above 'localised depletion' hypothesis is the basin model articulated by MacCall (1990). This model refers to the situation where the spatial distribution of a resource contracts to a core habitat region as the total population size diminishes. It is possible that the ‘core’ habitat (if one exists) for the swordfish population off eastern Australia is located away from the inshore regions first fished off Mooloolaba. If so, as the swordfish population has been reduced in size due to fishing and contracted to the core area, abundance and catch rates in the
peripheral areas (eg. the inshore regions) away from the core would have shown the greatest decline while catch rates closer to the core region would have been maintained.

Other hypotheses can also be invoked in order to explain the sequential decline in catch rates reported above. For example, limited research to date (Young et al, in press) has shown there is a relationship between swordfish catch and the environment on the east coast of Australia, supporting hypotheses applied by fishers for many years, and reported by other researchers elsewhere (e.g. Podesta et al, 1993; Bigelow et al, 1999). It remains possible, therefore, that spatial shifts in the distribution of the swordfish resource may have occurred in response to changes in regional environmental and/or oceanographic conditions. For example, the decreasing catch rates witnessed in the inshore regions may be due to the 'core' swordfish habitat moving further offshore (or further north or south). However, there remains much uncertainty about the role environmental variation plays in the spatial distribution and in the seasonal and long-term abundance of swordfish off eastern Australia.

Finally, it is possible that the vessels which pioneered the swordfish fishery off Mooloolaba were those with skilled crews who were able to obtain high catch rates. As the fishery developed and other vessels began fishing in the region, overall catch rates (especially in the inshore regions) may have dropped due to the presence of less efficient vessels with less skilled crews and the increased concentration of effort. As this occurred, the more skilled vessels began to fish further offshore where they were able to maintain the higher overall catch rates. This process may have been repeated over the years, with the more efficient vessels continuing to fish further offshore with catch rates closer inshore being driven down by the sequential replacement and increased presence of less efficient vessels.

4. Size Structure

A size monitoring program has been collecting data on the processor measured weights of individual swordfish since mid-1997. Weights have been collected for about eighty-percent of all fish landed since this time. Given the observed changes in catch rates in the fishery, it is interesting to see if there has been any corresponding change in the size distributions of landed swordfish.

The mean quarterly weight of the swordfish measured at processors in Mooloolaba is shown in Figure 6. For the seventeen quarters for which data are available, sample sizes have varied between 2000 and 6000 fish whilst the mean weight of swordfish has averaged between 46.7 and 62.4 kg. Mean weights are generally higher during the second half of the year. The 95th percentile weight of fish sampled (the weight of the 0.95N-th fish after ordering the fish in the sample into ascending size, where N is the number of fish in the sample, and is referred to here as the Upper-5th) is also shown in Figure 6 and has varied between 102.2 and 135.9 kg. The strong seasonal cycle in the weight distributions makes it difficult to discern a progressive change in size structure over time, though there is a decrease in mean weights during the first half of 2001. However, this decrease appears to be a consequence of large recruitment in the previous few years and not the diminution of larger sized fish. Furthermore, changes in size structure in the inshore regions (where the declines in catch rates are the greatest) may be masked in these present results, as they are based on samples of the fish caught across all areas of the "Brisbane Grounds". Further analysis, based on linking the size data to the locations where the fish have been caught during each trip (as recorded in logbooks) is required.
5. Discussion and Further Research

The above results suggest a sequential pattern of declining catch rates of swordfish off eastern Australia, especially in the inshore regions. If this pattern of 'localised decline' continues to be observed in future years there may be negative consequences to the viability of the longline fishery and possibly for the swordfish populations in this region. In particular, the economic viability of smaller vessels (which are unable to venture out to the offshore regions) could be significantly impacted if catch rates inshore continue to decline. This would have significant management implications and may raise the need for some form of spatial management. Furthermore, several of the hypotheses presented above to explain the temporal change in catch rates also have implications for our understanding of the spatial distribution and the movement dynamics of a 'highly migratory' species such as swordfish.

The above results, however, remain tentative in that the present analyses are based on nominal catch rates. The Australian longline fishery off eastern Australia targets a number of species (principally yellowfin and bigeye tuna together with swordfish) so there is a need to account for the multi-species targeting behaviour of the fleet before fully accepting the results presented here. Information contained in logbooks of individual vessels is presently being analysed to identify swordfish targeted effort in the fishery and any other changes in fleet behaviour which may have influenced swordfish catch rates.

Additional research is also presently underway to investigate the role played by each of the hypotheses outlined above in accounting for the observed patterns of declining catch rates. As each of the hypotheses gives quite different reasons for the observed declines in catch rates, the management response required in each case will also be quite different. In particular, as information about the nature of the environment-swordfish relationship is vital for interpreting perceived changes in catch and justify possible management responses, this study will investigate the dominant environmental and topographical influences on the abundance of swordfish in this region. As an example of one of mechanisms that may be helping to concentrate swordfish around seamounts, the project will investigate the possibility of localised regions of enrichment being formed around seamounts due to the existence of Taylor columns. A discussion of Taylor columns, and the role they may play in the ecology of seamounts, is given in an Appendix to this paper.

Similar patterns of declining catch rates of swordfish in localised regions have also been reported in the swordfish fishery off Reunion (M. Taquet, pers. comm.). This fishery is of a similar size to the swordfish fishery off eastern Australia (~2000 mt), and both fisheries occur at similar latitudes on the western side of a large ocean. Reasons for the observations in the Reunion fishery remain unexplored at present. However, due to the similarities between the two fisheries, this project will investigate the possibility of similar explanations accounting for the observed pattern of declining catch rates in the two fisheries. Furthermore, as the Reunion fishery developed earlier than the Australian fishery (and consequently has a longer time-series of catch and effort data) there may be lessons which can be learnt from this fishery which will assist in the understanding and management of the fishery off eastern Australia.

References


Taylor, G. I. (1917) Motions of solids in fluids when the flow is not irrotational. *Proceedings of the Royal Society A*, 93, 99-113
Appendix: Seamounts and Taylor columns

Seamounts interact with oceanic currents and create flow complexities that depend upon current speed, stratification, latitude and seamount morphology. Seamount effects include internal wave formation, eddy generation, and closed circulation patterns, called Taylor columns (Boehlert 1987). Until 1980 Taylor columns had only been theoretically predicted and indirectly inferred (Taylor, 1917). Owens and Hogg (1980) provided the first evidence for a Taylor column in the ocean for a seamount in the Gulf Stream at a depth of 4000-5000 meters.

Flow modification can have important effects on the pelagic and benthic ecosystems over seamounts. Effects that extend into the water columns may include retention of biota and enrichment of the water with regard to nutrients. Genin et al. (1989) measured near-bottom currents at the summits of Feiberling Guyot (32°26' N, 127°46' W) and observed elevated biological production above the seamounts, in particular an increase in density of benthic filter-feeders where currents were fastest. Genin and Boehlert (1985) found enhanced phytoplankton abundance over seamounts, suggesting uplifting of the nitricline as a mechanism. Dower et al. (1992) found a several-fold increase in the standing crop of chlorophyll a centered over the circular shaped Cobb Seamount (46° 45' N, 130° 48' W). Increased productivity above a seamount could be transferred to benthic and higher trophic levels (Dower et al. 1992). Maintenance of high standing stocks of seamount-associated micronekton and demersal fishes suggests that seamounts are locations for high rates of energy transfer (e.g. Boehlert 1987, Genin et al. 1988, Haury et al. 1994, Koslow et al. 2001). Increased abundance of pelagic fishes above seamounts has also been reported (Holland et al, 1999).

Biological data has the potential to identify the presence of retaining mechanisms on seamounts, such as Taylor columns. The vertical extent and residence time of Taylor columns can also be estimated by biological properties. For example, to form a chlorophyll maxima above a seamount requires a residence time on the order of days to weeks (Genin and Boehlert, 1985), which in turn requires a steady flow of water past the seamount. Increased concentrations of copepod carcasses over seamounts have also been suggested as indicators of Taylor columns (Haury et al. 1995). Finally, while in situ sampling tools such as CTD, ADCP and moored profiling instruments, acoustically tracked subsurface drifters and satellite surface drifters have been the primary methods of data acquisition to date, remotely sensed satellite data (SST, CHL and currents) may also be used to sample and identify retentive properties of seamounts.

While a growing number of observations suggest the presence of Taylor columns, and theory predicts their formation, nevertheless it is difficult to be certain. This is due to the complexity of the ocean, limitations on the scale of observations and measurements and inadequate understanding of flow over seamounts in realistic situations (Chapman and Haidvogel, 1992).
Table 1. Total annual retained catch of yellowfin, bigeye and swordfish and associated effort for the Australian longline fleet operating off eastern Australia.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sets</th>
<th>Boats</th>
<th>Squares</th>
<th>Hooks</th>
<th>Yellowfin</th>
<th>Bigeye</th>
<th>Swordfish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>2,267</td>
<td>98</td>
<td>92</td>
<td>1,147,471</td>
<td>676</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>1991</td>
<td>3,256</td>
<td>96</td>
<td>138</td>
<td>1,684,859</td>
<td>696</td>
<td>27</td>
<td>64</td>
</tr>
<tr>
<td>1992</td>
<td>3,361</td>
<td>105</td>
<td>128</td>
<td>2,095,250</td>
<td>882</td>
<td>34</td>
<td>52</td>
</tr>
<tr>
<td>1993</td>
<td>2,947</td>
<td>84</td>
<td>95</td>
<td>1,664,206</td>
<td>626</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>1994</td>
<td>3,988</td>
<td>88</td>
<td>129</td>
<td>2,738,543</td>
<td>977</td>
<td>108</td>
<td>41</td>
</tr>
<tr>
<td>1995</td>
<td>5,058</td>
<td>104</td>
<td>155</td>
<td>3,768,367</td>
<td>1,254</td>
<td>178</td>
<td>74</td>
</tr>
<tr>
<td>1996</td>
<td>6,252</td>
<td>121</td>
<td>162</td>
<td>4,490,191</td>
<td>1,649</td>
<td>307</td>
<td>692</td>
</tr>
<tr>
<td>1997</td>
<td>8,759</td>
<td>138</td>
<td>170</td>
<td>6,176,674</td>
<td>1,532</td>
<td>902</td>
<td>1,557</td>
</tr>
<tr>
<td>1998</td>
<td>11,429</td>
<td>151</td>
<td>207</td>
<td>9,656,684</td>
<td>1,851</td>
<td>1,032</td>
<td>1,775</td>
</tr>
<tr>
<td>1999</td>
<td>11,548</td>
<td>152</td>
<td>246</td>
<td>10,201,860</td>
<td>1,578</td>
<td>792</td>
<td>1,890</td>
</tr>
<tr>
<td>2000</td>
<td>11,050</td>
<td>140</td>
<td>249</td>
<td>9,505,158</td>
<td>1,562</td>
<td>689</td>
<td>1,939</td>
</tr>
<tr>
<td>2001</td>
<td>11,723</td>
<td>140</td>
<td>231</td>
<td>10,476,636</td>
<td>2,421</td>
<td>1,208</td>
<td>1,967</td>
</tr>
</tbody>
</table>

Table 2. Swordfish catch (tonnes) and associated effort on the "Brisbane Grounds" off central-eastern Australia for Australian longliners. The catch and effort is also expressed as a percentage of the total catch and effort for the entire fleet off eastern Australia.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sets</th>
<th>%Total</th>
<th>Squares</th>
<th>% Total</th>
<th>Hooks</th>
<th>%Total</th>
<th>Catch</th>
<th>%Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>731</td>
<td>32%</td>
<td>33</td>
<td>36%</td>
<td>246,542</td>
<td>21%</td>
<td>5</td>
<td>19%</td>
</tr>
<tr>
<td>1991</td>
<td>744</td>
<td>23%</td>
<td>54</td>
<td>39%</td>
<td>366,395</td>
<td>22%</td>
<td>9</td>
<td>14%</td>
</tr>
<tr>
<td>1992</td>
<td>697</td>
<td>21%</td>
<td>57</td>
<td>45%</td>
<td>500,327</td>
<td>24%</td>
<td>15</td>
<td>29%</td>
</tr>
<tr>
<td>1993</td>
<td>654</td>
<td>22%</td>
<td>32</td>
<td>34%</td>
<td>291,934</td>
<td>18%</td>
<td>3</td>
<td>10%</td>
</tr>
<tr>
<td>1994</td>
<td>726</td>
<td>18%</td>
<td>43</td>
<td>33%</td>
<td>450,153</td>
<td>16%</td>
<td>12</td>
<td>29%</td>
</tr>
<tr>
<td>1995</td>
<td>1,522</td>
<td>30%</td>
<td>59</td>
<td>38%</td>
<td>1,089,950</td>
<td>29%</td>
<td>41</td>
<td>56%</td>
</tr>
<tr>
<td>1996</td>
<td>2,196</td>
<td>35%</td>
<td>59</td>
<td>36%</td>
<td>1,398,787</td>
<td>31%</td>
<td>560</td>
<td>81%</td>
</tr>
<tr>
<td>1997</td>
<td>4,463</td>
<td>51%</td>
<td>76</td>
<td>45%</td>
<td>3,383,425</td>
<td>55%</td>
<td>1,429</td>
<td>92%</td>
</tr>
<tr>
<td>1998</td>
<td>5,922</td>
<td>52%</td>
<td>86</td>
<td>42%</td>
<td>5,276,670</td>
<td>55%</td>
<td>1,436</td>
<td>81%</td>
</tr>
<tr>
<td>1999</td>
<td>7,094</td>
<td>61%</td>
<td>115</td>
<td>47%</td>
<td>6,609,995</td>
<td>65%</td>
<td>1,617</td>
<td>86%</td>
</tr>
<tr>
<td>2000</td>
<td>6,919</td>
<td>63%</td>
<td>125</td>
<td>50%</td>
<td>6,496,879</td>
<td>68%</td>
<td>1,620</td>
<td>84%</td>
</tr>
<tr>
<td>2001</td>
<td>7,275</td>
<td>62%</td>
<td>114</td>
<td>49%</td>
<td>6,935,641</td>
<td>66%</td>
<td>1,464</td>
<td>74%</td>
</tr>
</tbody>
</table>
Figure 1. Map of the south-west Pacific showing the location of the "Brisbane Grounds" (24-34°S, 152-164°E) off eastern Australia.

Figure 2. Annual Australian longline effort (columns) and associated nominal swordfish catch rates (line) on the "Brisbane Grounds" off eastern Australia.
Figure 3. Spatial distribution of annual swordfish catch rates on the "Brisbane Grounds" for each year between 1995 and 2000. Same scale used each year.
Figure 4. Plots of mean effort (1000s of hooks) within those 1-degree squares on the "Brisbane Grounds", which for each indicated year, have been fished for \( n \) of the years between 1995 and 2001. Individual results are shown for each year between 1996 and 2001.

1996  
1997  
1998  
1999  
2000  
2001

Figure 5. Plots of mean nominal catch rate of swordfish within those 1-degree squares on the "Brisbane Grounds", which for each indicated year, have been fished for \( n \) of the years between 1995 and 2001. Individual results are shown for each year between 1996 and 2001.

1996  
1997  
1998  
1999  
2000  
2001
Figure 6. Mean (and upper 5\textsuperscript{th} percentile) dressed weight of swordfish landed at Mooloolaba by year and quarter.