POSSIBLE IMPACTS OF THE GREENHOUSE EFFECT ON THE DISTRIBUTION AND FISHERIES OF PELAGIC FISHES OFF SOUTH-EASTERN AUSTRALIA

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INTRODUCTION

Predictions of Greenhouse related rises in global temperature have to date mainly concentrated on air temperature. Very few extrapolate to likely effects on ocean temperatures, other than to suggest that these also will rise, albeit after some time-lag due to heat transfer effects. Sea level rises are predicted on the basis of two effects, both related to temperature: melting of the polar ice caps (long term) and, more immediately, thermal expansion of the oceans due to an overall increase in water temperature. Given that global air temperature is predicted to rise by 2-4°C by the year 2030, a rise in average sea surface temperature of about 3°C for midlatitudes is fairly widely predicted (Stark 1988, De Sylva 1989).

In this event, the marine fishes most likely to be immediately affected would be those which inhabit the surface layers of the ocean, the many and varied pelagic species. While a number of such species are small schooling fish, the so-called bait fishes, I will confine this paper to the potential impacts of the Greenhouse effect on the larger predatory fishes of the surface layer, and in particular the tunas and billfishes. These are of special concern since they form the basis of very important existing commercial and recreational fisheries off eastern Australia.

The distribution of the tunas (family Scombridae) and billfishes (family Istiophoridae) is very extensive. Most species range across the tropical and/or temperate regions of whole oceans, and some, such as the albacore, yellowfin, bigeye, southern bluefin and skipjack tunas, occur in all three major oceans (Collette & Nauen 1983).

The boundaries of the distributions of tunas and billfishes shift seasonally, moving polewards in summer in each hemisphere and towards the equator in winter (Nakamura 1965). These seasonal changes in distribution over wide areas are usually assumed to be directly linked to sea surface temperature (e.g. Blackburn 1965), and many studies have shown strong correlations between surface temperature and concentrations of tunas and billfishes. For example, Squire (1974) showed such a relationship for striped marlin off southern California. Figure 1 is taken from that study and shows that striped marlin were caught over a relatively narrow temperature range, with a strong preference at 20°C. Squire & Nielsen (1983) showed a similar relationship for black marlin off north-eastern Australia, and Pepperell & Diplock (1990) have demonstrated that yellowfin tuna are generally found at water temperatures above 21°C off south-eastern Australia.

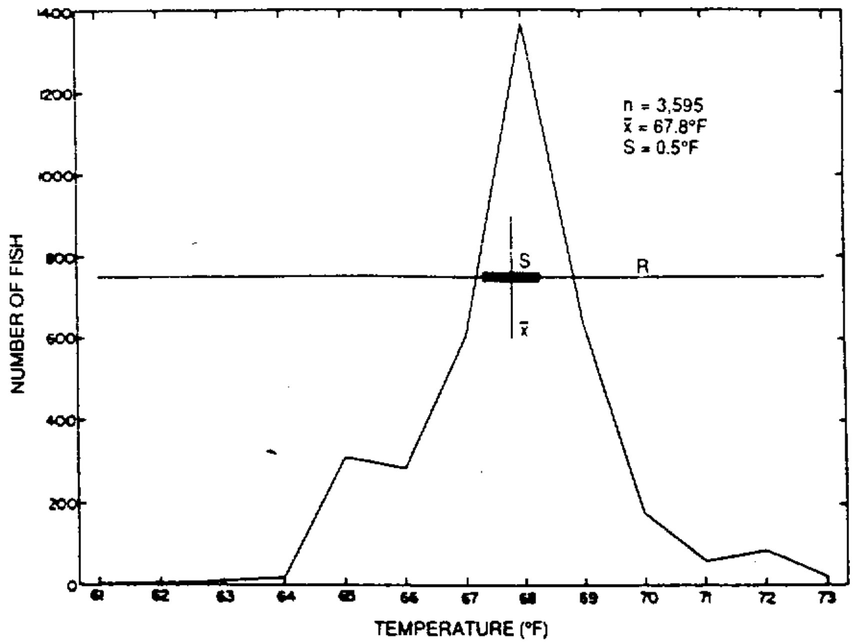

Figure 1 Distribution of striped marlin by sea surface temperature for all catches of the San Diego Marlin Club, California (1963-1967). (from Squire 1974)

Tracking tuna and billfish with sonic transmitting tags has shown that they remain within the upper mixed layers, actively avoiding colder, deeper water (Carey & Olsen 1982, Brill *et al.* 1984, K. Holland per. comm.).

This discussion of possible Greenhouse effects on pelagic fishes will be restricted to the east coast of Australia, where the surface fisheries are much more developed than off the west coast. Some of the scenarios outlined would nevertheless be equally probable in the west.

Figure 2a shows the average peak summer sea surface isotherm pattern for Australia, while Figures 2b and 2c show the simplest situation if temperature increases of 2°C and 4°C respectively were to occur in a uniform way. From this simplest set of cases, it is clear that warmer water would bathe more southern parts of the Australian coast. In particular, water with temperatures in the range of 20 to 22°C would almost certainly flow through Bass Strait and across the southern part of the continent. This fact, together with the general shift of warmer water several hundred kilometres polewards, would have major effects on the distributions of pelagic fishes, and on the fisheries which target them.

Good sea surface temperature data are available for south-eastern Australia over recent years, courtesy of the Royal Australian Navy Weather Station at Nowra. It is, therefore, useful to concentrate on that area in attempting to predict future changes due to temperature shifts.

Figure 3 shows the peak summer and winter sea surface isotherms for two recent years, 1986/87 and 1988/89. These years were chosen to show a 'normal' year (1986/87) and, importantly, a year in which much warmer than normal temperature patterns occurred (1988/89).

In the latter year, water much warmer than normal flowed considerably further southwards than usual, as can be seen in Figure 3c by the mass of very warm water located off north-eastern Tasmania and extending into Bass Strait. Yellowfin tuna were caught from oil rigs in Bass Strait in early 1989, and the domestic longline fleet followed yellowfin southwards as far as the Tasmanian coast. The game fishing season off southern Queensland and New South Wales was also most unusual during the summer of 1988/89. Table 1 summarises the numbers of certain gamefish species tagged off eastern Australia during that year, compared with the previous three 'normal' years (source: Annual Tagging Reports, NSW Fisheries Research Institute). Even though no fishing effort data are available, it is clear that large increases in the availability of key species of tunas and billfishes occurred during that time. Of special note was the occurrence of large numbers of blue marlin off New South Wales, an event not previously recorded in historic game fishing club reports. In addition, capture records from gamefishing clubs show that twelve sailfish were caught in New South Wales waters in 1988/89, compared with less than ten for the previous twenty years combined. No explanation of this phenomenon is offered here, other than to suggest the possibility of an 'El Nino' related effect. The results of this unusual season are presented as a possible foretaste of 'normal' events which may exist under Greenhouse conditions.

	1985/86	1986/87	1987/88	1988/89
Black marlin	937	1735	957	1024
Blue marlin	16	4	44	135
Striped marlin	17	44	32	119
Spearfish	0	0	0	4
Yellowfin tuna	692	630	1102	2233
Skipjack tuna	549	762	741	981

Table 1. Numbers of selected species of billfishes and tunas tagged off eastern Australia by recreational anglers.

Squire (1983), examined historic sea surface temperature records and recreational and commercial catches of pelagic fishes off southern California to determine the effects of El Nino on the distribution and abundance of these fishes. The most intensive El Nino during that period was in 1957/58, during which time average sea surface temperatures were 4-6°F above the long term mean. During that time, southern Californian catches of many species of fish greatly increased, in particular yellowtail kingfish, Pacific bonito, barracuda, skipjack tuna, dolphin fish and striped marlin. Only one pelagic species appeared to be negatively affected - the albacore. Squire (1987) extended these observations to the strong El Nino year of 1983. He noted similar effects to those of 1957/58, but with a notable addition to the list of pelagic fishes affected. Whereas yellowfin tuna were usually an infrequent catch off southern California, in 1983 more than 89,000 yellowfin were reported caught by the San Diego commercial charter sportfishing fleet alone.

De Sylva (1989) also noted that strong El Nino events resulted in marked latitudinal displacements of not only pelagic fishes, but also invertebrates, birds, and marine mammals. He also predicted poleward expansion of billfish distribution due to global warming, and suggested that billfish distributions and isotherm patterns may be good indicators of the Greenhouse effect.

Therefore, with these types of background data and prior observations, it should be possible to predict potential gross effects of Greenhouse conditions for pelagic fishes and fisheries off the east coast of Australia. A range of species has been selected to indicate the scope of such potential effects. This is summarised in Table 2, and expanded below.

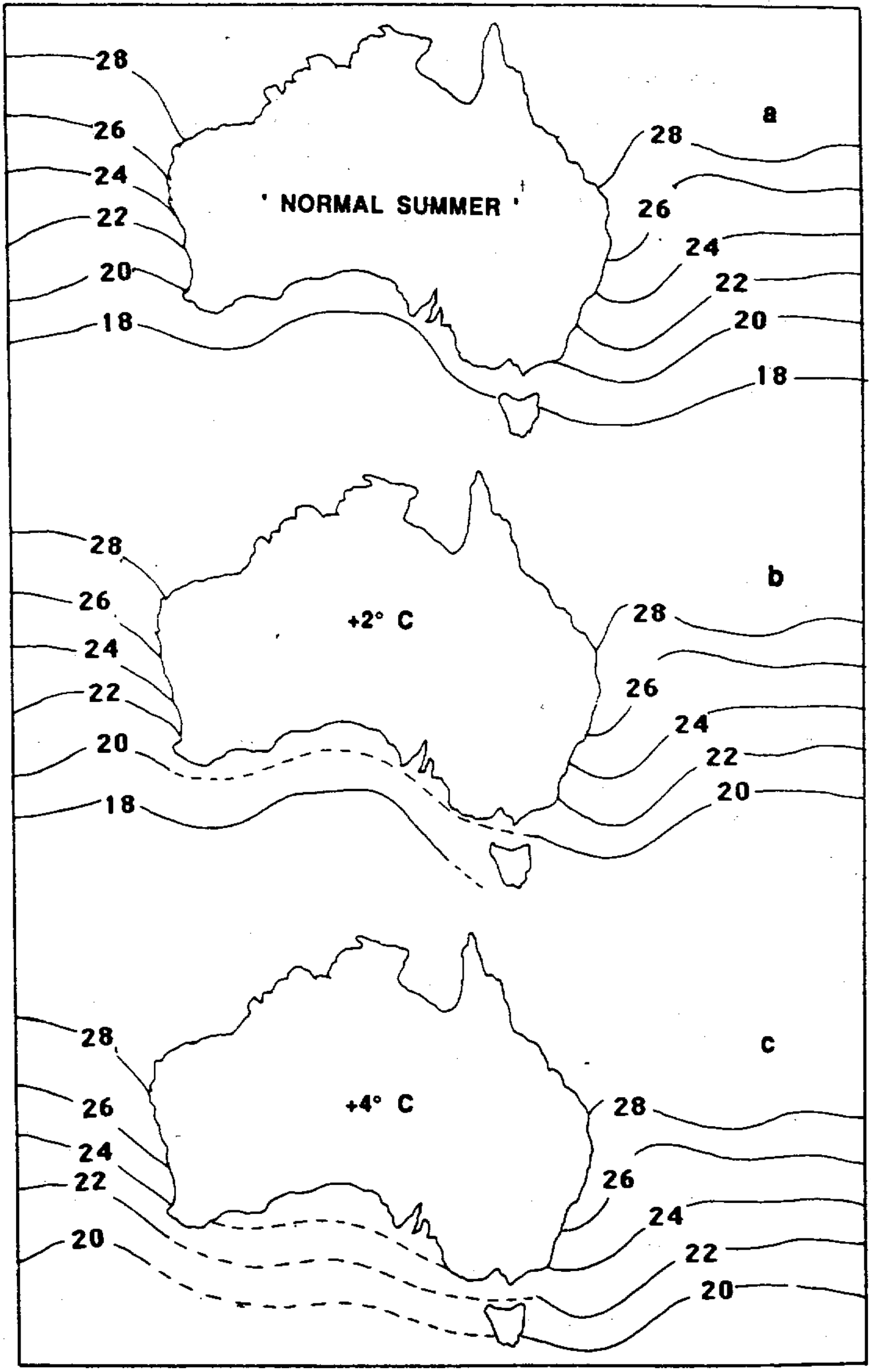

Figure 2a Sea surface isotherms off Australia in a 'normal' summer, February 1987 (modified after Stark1988).
2b Sea surface temperatures increased by 2°C.
2c Sea surface temperatures increased by 4°C.

ECIES	BIOLOGICAL EFFECTS	EFFECT ON FISHERIES
ack marlin	Large females found further to south. Expansion of spawning area. More common to south.	More by-catch in longline fishery. Better sport-fishing in NSW.
ue marlin	More common off NSW.	As above.
riped marlin	Less common off southern Queensland.	More bycatch in longline fishery. More common off Tasmania.
ilfish	Populations established further to south (e.g. Tweed Heads, Port Stephens).	New sport fisheries in NSW.
ellowfin tuna	Seasonal fishery further south, extending to Tasmania. Extended spawning areas to south. Appearing off South Australia.	Displace southern bluefin tuna. Purse seining in more southerly areas.
igeye tuna	Large adults distributed further south.	Longline fishery extends to Tasmania.
kipjack tuna	Southward expansion of range.	Purse seining fishery off NSW.
lbacore	Displaced further south.	Decline of fishery off NSW. Increase off Tasmania.
panish ackerel	Appears commonly south of present range limit.	New fishery in NSW. Ciguatera risk further to south.
'ellowtail ingfish	Distribution similar, but protozoan parasite rate increased through NSW.	Decline of commercial fishery due to parasites

able 2 Possible biological and fishery effects of Greenhouse changes on pelagic fisheries off eastern Australia.

OSSIBLE EFFECTS ON MAJOR PELAGIC SPECIES

lack marlin (*Makaira indica*)

Compared with other species of billfishes, the black marlin is relatively uncommon in Japanese longline catches hroughout the Pacific. However, it is the most common billfish caught by recreational anglers off eastern Australia Pepperell 1990). A pre-spawning aggregation of black marlin occurs off the Great Barrier Reef between Cairns and Lizard sland each spring (Squire & Nielsen 1983), and because of the large size of the females, attracts anglers from all over the vorld. Squire and Nielsen (1983) showed that the maximum Japanese longline catches of black marlin off north-eastern ueensland were always made between the 26°C and 28°C isotherms, shifting northwards and southwards seasonally. epperell (1990) demonstrated a southward movement of juvenile black marlin along the continental shelf from northern ueensland to the latitude of Sydney, which coincided with increasing water temperatures.

A change in sea surface temperature of 2 to 4°C then would almost certainly have the effect of moving the oncentration of adult fish southwards, and if temperature is the main cue for determining the latitude of the spawning grounds, may possibly even shift the main spawning area from wide of Cairns to perhaps wide of Townsville.

Juvenile black marlin would become more common in New South Wales waters, resulting on the one hand in better recreational angling, but on the other in a higher by-catch rate in the domestic tuna longline fishery.

Blue marlin (*Makaira nigricans*)

The blue marlin is the most tropical of the marlins (Nakamura 1974), and was thought not to occur off the east coast of Australia until the 1930s (Goadby 1987). Catches by domestic fishermen have been fairly rare until the last five years, when new game fishing techniques have revealed the existence of a good fishery wide of the continental shelf from at least Cape Moreton in southern Queensland to Bermagui in southern New South Wales. In fact, the blue marlin is now the most prized gamefish targeted off south-eastern Australia, due to the large sizes available (100-200 kg). Increased water temperatures would most probably increase the importance of this fishery, and also increase the incidence of capture of blue marlin in the south-eastern longline fisheries.

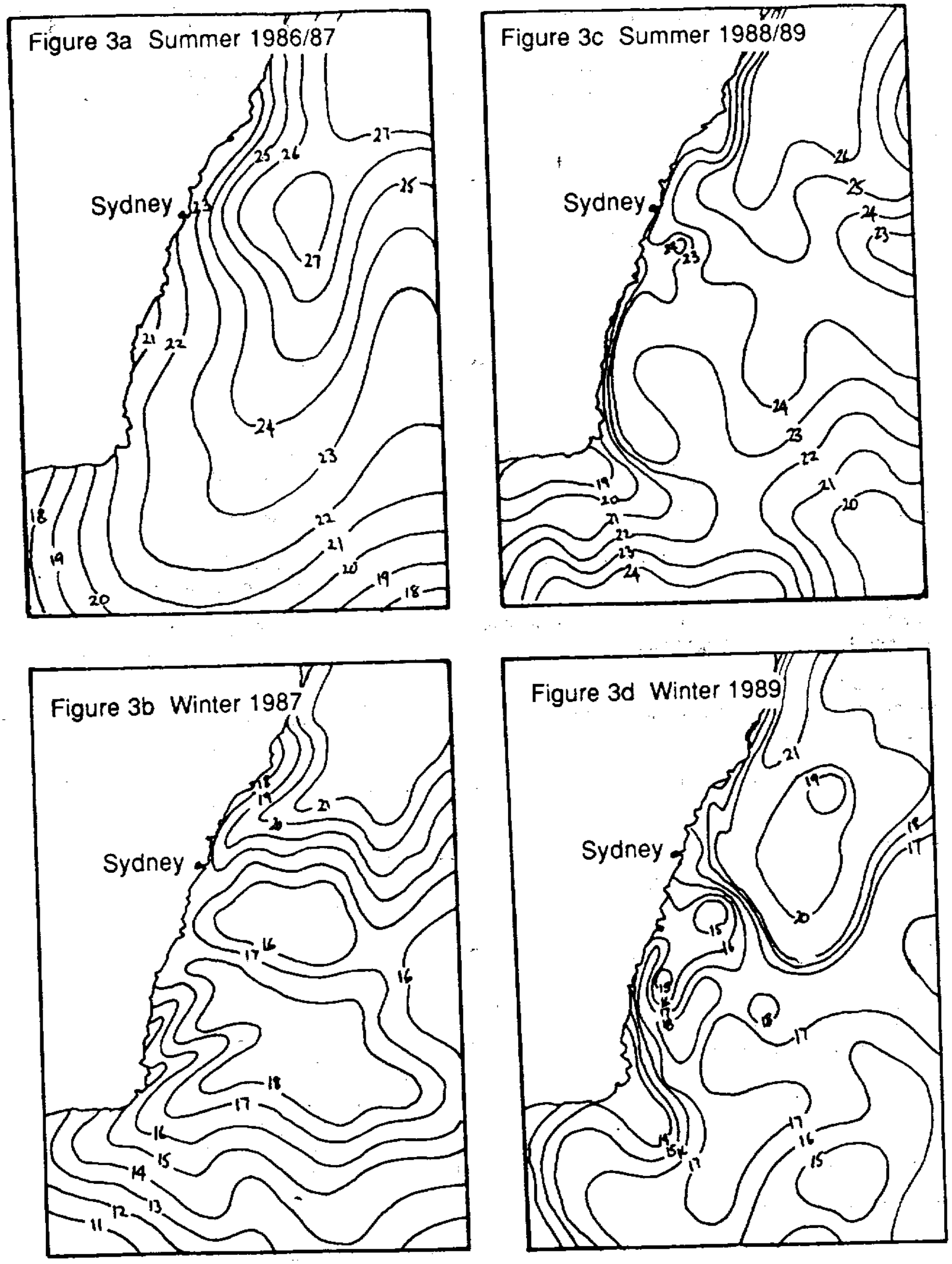

Figure 3 Sea surface isotherms off south-eastern Australia during peak summer and winter periods:
a) Summer 1986/87
b) Winter 1987
c) Summer 1988/89
d) Winter 1989

Striped marlin (***Tetrapturus audax***)

Striped marlin appear to be able to tolerate, or 'prefer', cooler temperatures than all other species of istiophorids. Their preferred temperature is about 20-21°C (Squire 1974, 1987) but they may be caught in water as cool as 16°C (fig. 1). Striped marlin are caught off southern Queensland and New South Wales by recreational anglers, and are the most common istiophorid species caught in the eastern Australian Fishing Zone by Japanese longliners (Pepperell 1985). Striped marlin are presently the only istiophorid caught off Tasmania, and presumably, under Greenhouse conditions, this would become a more common occurrence. As indicated in Figure 1, it is likely that sea surface temperatures through Bass Strait, and across the Great Australian Bight, would reach at least 20-21°C in late summer. It is therefore entirely likely that striped marlin could then move freely throughout this region, linking the Indian and Pacific Ocean populations.

Striped marlin are the most highly prized of the istiophorids caught by Japanese longliners, and are permitted to be taken for export by domestic fisheries. Increased by-catch and even new fisheries, both commercial and recreational, directed at this species, could be reasonably expected in southern waters.

Sailfish (***Istiophorus platypterus***)

There are three known areas off the east coast where sailfish concentrate and are the target of recreational fisheries: off Beaver Cay, near Dunk Island; off Cape Bowling Green, near Townsville; and off Cape Moreton, near Brisbane. In each case these aggregations of sailfish are associated with concentrations of baitfish, which in turn may be related to nutrient discharge from mangrove-rich regions (Williams 1990). Sailfish have the highest preferred temperature range of the istiophorids (Beardsley *et al.* 1974), but with a southerly shift in warmer sea-surface temperatures it is possible that populations could become established in suitable areas off New South Wales. Likely regions would be off the Tweed and Clarence Rivers, or even off Port Stephens.

Certainly, sailfish would appear more commonly in New South Wales waters, as happened during the summer of 1988/89, when at least twelve sailfish were captured off New South Wales, two as far south as Tathra and Merimbula.

Yellowfin tuna (***Thunnus albacares***)

Yellowfin tuna are found at water temperatures ranging from 18 to 31°C (Collette & Nauen 1983) but their optimum or preferred range is much less. The southern limit of distribution of yellowfin tuna along the eastern Australian seaboard is well correlated with sea surface temperatures of 20-22°C, and domestic commercial and recreational fisheries target this species at those temperatures (Pepperell & Diplock 1990). Some fish are caught in cooler water, but the bulk of the population off this coast remains near or to the north of this front, and shifts north and south with the mass of water at that temperature. Under Greenhouse conditions, this seasonally expanding and contracting wave of yellowfin tuna would move further south in summer and autumn, certainly moving consistently into Bass Strait, as indeed occurred during the unusually warm summer of 1988/89 (Pepperell, unpublished data). No data are available on movements of yellowfin tuna off Western Australia, but if similar behaviour occurs, then like striped marlin, there would be a high likelihood of mixing of stocks between the Indian and Pacific Oceans.

Bigeye tuna (***Thunnus obesus***)

This species of tuna is closely related to the yellowfin, and has a similar distribution. However, it is a deeper swimming fish, and prefers temperatures of 17 to 22°C, which coincide with the permanent thermocline with which it is usually associated (Collette & Nauen 1983).

While juvenile and adult bigeye tuna are caught in a seasonal handline fishery in the Coral Sea in spring (Hisada 1973), only adults (100 kg +) are caught by deep longlines off the New South Wales coast. Therefore, depending on the warming effect at greater depths, the Greenhouse effect could push the bigeye tuna fishery further south to, say, the east coast of Tasmania.

Albacore (***Thunnus alalunga***)

The albacore is a cold water species of tuna which has a broad distribution, but is abundant between temperatures of 15.6-19.4°C (Collette & Nauen 1983). Albacore appear in commercial and recreational catches off southern New South Wales in mid-winter, and under Greenhouse conditions could be expected to occur further south, perhaps off Tasmania. As noted, the albacore was the only pelagic species which showed a decrease in abundance off southern California during the strong 1957/58 El Nino event (Squire 1983).

Skipjack tuna (***Katsuwonis pelamis***)

Skipjack tuna are classified as a tropical species able to tolerate a wide range of temperatures from 14.7-30°C (Collette & Nauen 1983). A small pole-and-line fishery targets on skipjack off southern New South Wales in late summer, while recreational catch and effort extends from early summer through autumn, from about the latitude of Port Macquarie to that of Eden. Warmer surface temperatures would again be expected to expand the range of this species southwards. Some purse seining of skipjack has occurred off southeastern Australia in recent years, and this activity could increase under Greenhouse conditions.

Spanish mackerel (***Scomberomorus commerson***)

The southern limit of the range of Spanish mackerel on the east coast is quite marked, with very few fish extending south of South West Rocks. Increased surface temperatures could push this limit further south and open up ossibilities of new fisheries on this popular sport and table fish. The one drawback to this would be the possible increase n risk of ciguatera poisoning since some cases are known to have derived from eating Spanish mackerel caught in southern ueensland.

Yellowtail kingfish (*Seriola lalandi*)

This species belongs to the family Carangidae, and is not strictly pelagic like the tunas and billfishes. However, it does have a cosmopolitan distribution, and ranges from the Victorian border to about the latitude of Rockhampton. It is an important sportfish throughout its range, and commercially important south of about Coffs Harbour. However, fish found north of there often are infected with a protozoan muscle parasite which causes the flesh to become unpalatable when cooked (Lester 1982). While the range of yellowtail kingfish may not be affected to a large extent by the Greenhouse effect, it is quite likely that the infection rate of the protozoan parasite would extend several hundred kilometres further south, thereby having a disastrous effect on the existing commercial fishery.

CONCLUSION

Unusually warm water conditions in the past probably give strong clues as to gross effects of long term Greenhouse conditions, and many of the scenarios outlined are thought to be quite likely. However, it needs to be emphasised that other changes caused by global warming could well influence, or markedly alter, the magnitude, or even the direction, of these changes. Unknowns include effects on major ocean current systems, and possible changes in primary productivity as well as distribution of baitfishes. The 'El Nino' phenomenon may also be altered, and become either stronger or weaker. The volume of world oceans is predicted to increase substantially, which could theoretically lead to increased absolute abundance of pelagic fishes, especially since their world-wide distribution would expand considerably.

Whatever the realities of the scenarios described might be, it is clear that even small, long-term changes in the average temperatures of the ocean surface layers would have major effects of the distributions of these pelagic fishes and the important fisheries which rely upon them.

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