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THE NATURE OF OUR SEAS

B. V. HAMON

7 Robin Place, Caringbah, NSW 2229

The ocean areas around Australia show many parallels with the better-studied oceans of the Northern Hemisphere. In particular, the mechanisms that lead to high biological productivity in high latitudes are the same. But the details of current systems are often very different. Our south-flowing Leeuwin Current is unique, and the East Australian Current is a much less definite feature than its north Atlantic counterpart, the Gulf Stream. Upwelling plays relatively little part near Australia, so that our waters are not among the most productive in the world. These differences must have a great influence on the distribution and abundance of seabirds in Australian waters, but detailed studies of this influence are only just beginning.

INTRODUCTION

As a major part of the world we live in, the seas deserve our attention. They control our climate: the recent severe drought (and even more recent floods) in most of eastern Australia appear to be linked to changes in the ocean throughout the whole equatorial Pacific. We are increasing our exploitation of the seas and of the minerals, oil and gas beneath them.

Scientists have been studying Australia's seas for decades, but the total effort has been small. Field work in the open ocean is difficult, slow and expensive. The oceans are opaque to everything except sound waves, so we are forced to sample blindly from tossing ships, using crude mechanical sampling devices, in a medium which is itself always moving. No wonder this sampling has been compared to trying to do astronomy by looking up from the bottom of a deep well — once every few months! But a good start has been made, mostly using naval vessels in the 1960's and 70's, and chartered vessels more recently. Satellites are being used, and their ability to look at vast areas almost instantly is valuable, but they should be regarded as supplementary to the more traditional ship sampling.

THE EARLIEST SEAS

If we go back 4 000 million years or so, to the beginning of planet Earth, it is believed the seas were already there. It is not clear how they escaped being lost to space during the initial stages of forming the planet, as apparently happened on Mercury and Mars, but water-worn pebbles in some of the oldest rocks suggest that seas (and land) were around before these rocks were formed. It is likely that the seas at that time were even more dominant than at present, probably covering 85 per cent of the Earth's surface, compared to the 71 per cent at present.

With the seas so old, it is a paradox that the sea floor is relatively young! The most important advance in geophysics in the past 50 years has been the realization that the floor of the ocean is moving sideways — and carrying the continents along with it — at measureable rates. The rocks underlying the recent sediments, and forming the true floor of the ocean, are thus not more than a few hundred million years old. They are igneous rocks, formed by lava that rises under the curious mid-ocean ridges.

The drifting 'plates' of ocean bedrock, carrying the continents piggy-back, have to go somewhere. Some are believed to bury themselves beneath other continents, forming the world's more spectacular mountains in the process. The burying of other plates accounts, again paradoxically, for the deepest parts of the ocean — the narrow, deep ocean trenches.

Where does Australia stand in this shifting system? Together with Antarctica, Australia once formed part of a larger continent, which has been named *in absentia* 'Gondwanaland', and which began to split up some hundreds of millions of years ago. Australia, and its surrounding plate of ocean bedrock, is now believed to be moving north at a stately centimetre or so per year, having left Antarctica only about 75 million years ago. So large-scale world geography as we know it — including the depths and extent of deep-sea regions around Australia — is not very old as geologists measure time.

There have been many changes in the oceans on much shorter time scales. The most important are the changes in mean sea level. The total quantity of water-plus-ice does not change, but the part of it that is locked up in glaciers and ice sheets varies greatly, and has a big effect on sea level. In the depths of the last major ice age, a mere 15 000 years ago, sea level was 100–150 metres below its present level. Its recovery towards present levels has been in stages, and some features of the shape of the bottom on continental shelves around Australia are relics of ancient shores.

Sea level has been relatively stable for the past few thousand years, rising at a rate of a few centimetres per century. For comparison, its maximum rate of rise after the last ice age was about two metres per century. Sea level changes are measured by the tide gauges maintained in most harbours for navigation purposes, and interest in estimating such changes from the records is increasing.

CURRENTS

Water movements in the oceans — 'currents' — are of the greatest importance. It is hard to imagine any marine topic, scientific or practical, where the fact that we are dealing with a liquid, which can and does move, is not central to our understanding.

On a large scale, ocean currents move heat, on average from the tropics towards the poles; this is of utmost importance in the complex interaction between sea and air that determines our climate. Currents are also responsible for dilution of the many effluents we discharge into the sea. They carry marine plants and animals, and distribute their eggs and larvae. They bring food to the very mouths of animals who prefer to sit and wait for it to come.

The major ocean basins of the world have their own large-scale current systems, driven by the trade winds near the Equator and the westerlies at higher latitudes. These current systems flow clockwise in the Northern Hemisphere, and anticlockwise in the Southern Hemisphere (Fig. 1). Due to the earth's rotation, the circulating currents are narrower and more intense on the western sides of all oceans, in both hemispheres.

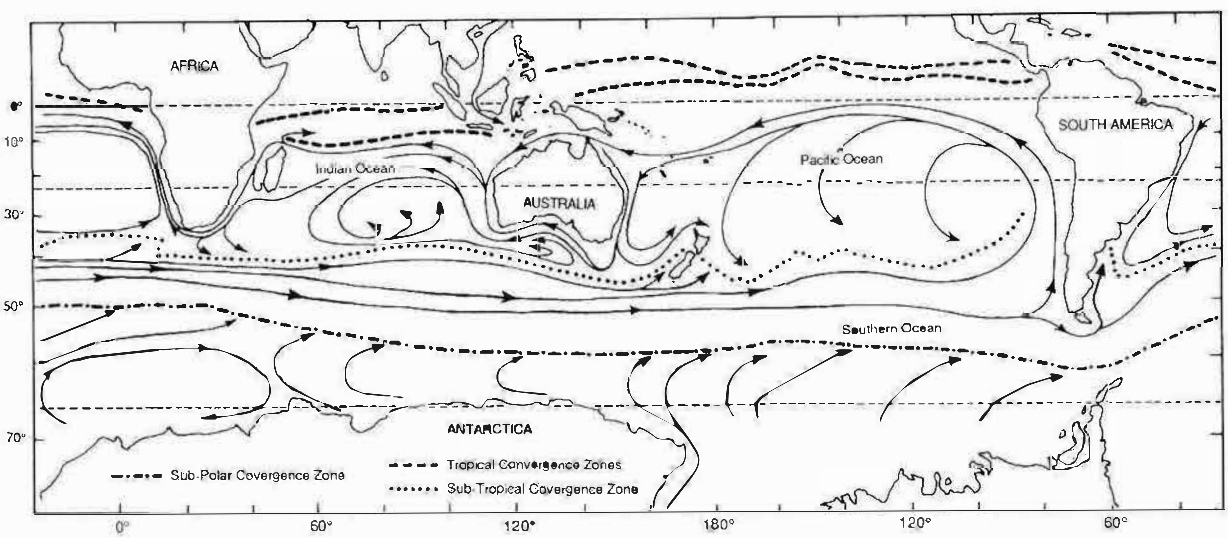

Figure 1. *Map of Southern Hemisphere surface currents. Convergence zones, where surface waters tend to sink, are also shown. (Adapted from CSIRO Fisheries and Oceanography Research Report, 1974–77).*

This system leads us to expect a strong narrow southward current off east Australia, and a broader northward flow off Western Australia. There is little evidence for the latter, and although the expected current off east Australia (the East Australian Current) has been known from the early sailing ship days, recent work shows that it has some unexpected features.

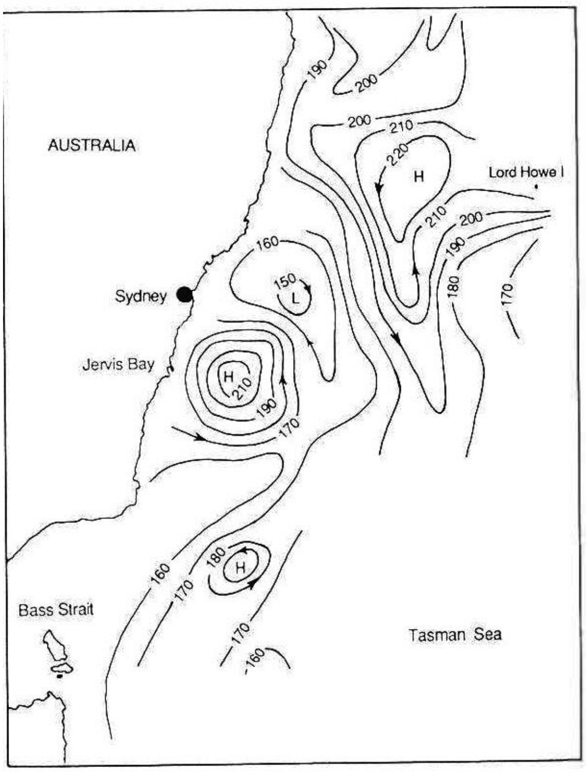

Figure 2. *Map of sea surface height off east Australia in January–February 1964. Measurements of the water density at various depths were made at many stations positioned in a grid over the sea. The heights were calculated from the densities. Arrows show direction of currents. The currents are stronger where the lines are closer together. The map shows an eddy off Jervis Bay, and the suggestion of another off Bass Strait. As often found, the East Australian Current is not particularly clear. (Adapted from Deep-Sea Research, vol. 12, 1965, p. 905).*

The eddies are about 200-300 km in diameter. The associated currents are a leisurely 2 metres per second, but this is fast for open-ocean currents. Since the currents are wide (about 100 km) and deep (to 1 000 metres or more but strongest near the surface), they transport a lot of water — more than the largest of rivers. But the eddy structure means that most of the water keeps going round and round, making the long-term and large-scale effects of the current system hard to predict. There is some evidence that the eddies move slowly south, but they can remain stationary for months, and even move back north. Sometimes they coalesce.

Much of the work on the currents and the eddies discussed above has been done using an indirect method, called the 'dynamic' or 'geostrophic' method. Your ship covers the area of interest, stopping every 100 km or so to measure the temperature and salinity to at least 1 500 m depth. The water is found to be warmer on average, and therefore less dense (lighter), at some places than at others. Where it is warmer the ocean surface should be higher (up to 1 m). Maps of these small height differences are drawn; they look like weather maps and can be interpreted in the same way, with currents replacing winds. An eddy off the east coast shows up as a 'high' on such maps, with the centre up to 70 or 80 cm higher than the edges. Currents must flow anticlockwise round such a high, just as winds blow anticlockwise round a high on the weather map — and for the same reason, which is related to the rotation of the earth. Figures 2 and 3 show features of the circulation off east Australia, revealed by the above method.

Similar eddies are present off Western Australia, but the currents associated with them are weaker, and both clockwise and anticlockwise eddies are found. The broad, slow movement of water to the north, predicted by analogy with the Northern Hemisphere ocean basin circulations, may be present but has not yet been documented.

The most interesting feature of circulation off Western Australia is the recently-discovered Leeuwin Current, whose direction of flow is southward — opposite to the expected flow. The Leeuwin Current is present only in winter. It is a narrow current near the shelf edge, from North West Cape to Cape Leeuwin, and thence around the

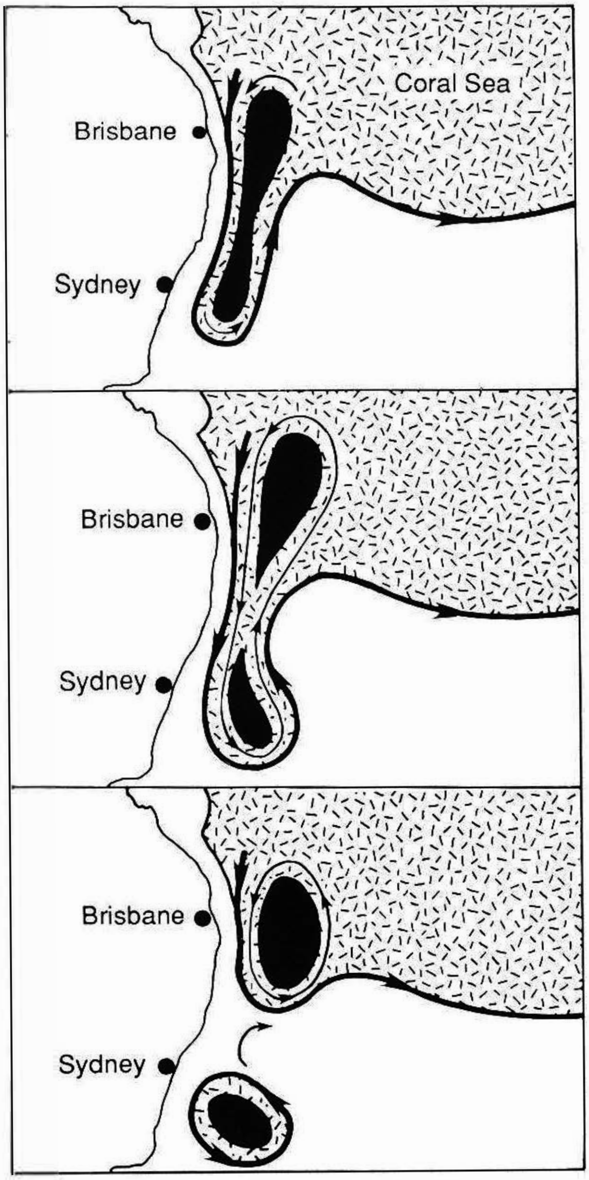

Figure 3. *Schematic map of sea surface height off east Australia showing how an eddy (such as the one shown off Jervis Bay in Figure 2) was probably formed by extention southward of a ridge, followed by pinching off. The dark and stippled areas indicate higher water heights. (Adapted from CSIRO Research in Australia, No. 14: Oceanography, 1987).*

south-west corner and into the Australian Bight. Its existence helps to explain the nature of shelf and near-shore marine plants and animals in the Bight (Figure 4).

Off the south of Australia there do not seem to be any currents worth naming. The only exception is off the west coast of Tasmania — but here there is confusion. Some say the flow is northward, and have called it the 'Flinders Current', while more recently a southward flow has been

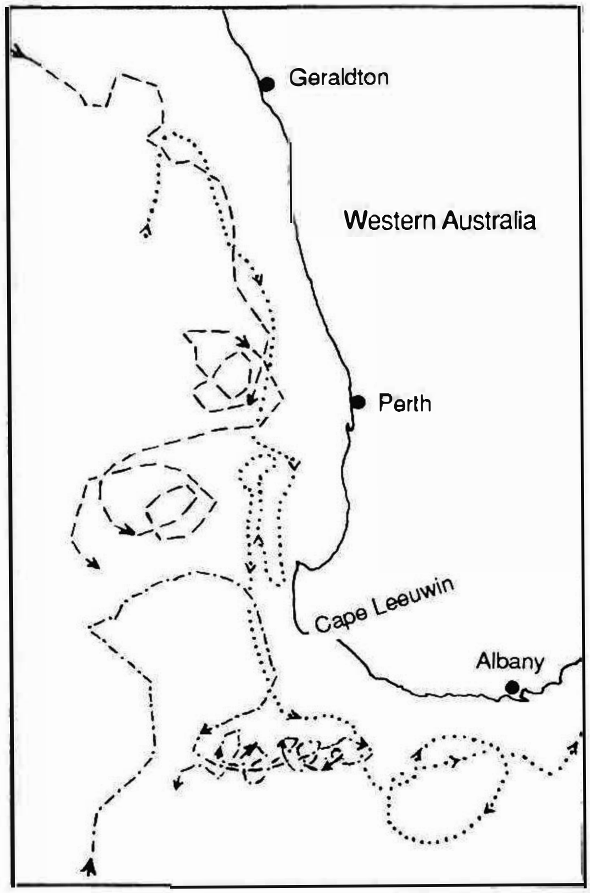

Figure 4. *Ocean currents are often studied by releasing drifting buoys, which are tracked by satellite. This figure shows the tracks of three buoys off south-west Australia in March–June 1976. The tendency for the buoys to get trapped in eddies can be seen clearly, especially south-west of Perth. The southward movements near the shelf edge, which is approximately 50 km offshore, are due to the Leeuwin Current. (Adapted from CSIRO Marine Laboratories Research Report 1979–1981).*

claimed, and called the 'Zeehan Current'. Well south of Tasmania lies one of the great currents of the world — the West Wind Drift, or Circumpolar Current. It links the southern parts of the Atlantic, Pacific and Indian Oceans. It is too far south to have much direct effect on Australian waters, though the indirect effects must be great.

What about the north? The North-west Shelf has been studied since oil and gas exploration started there, but no large-scale current has been named in the area, unless we count the South Equatorial Current — a basin-wide feature of the whole Indian Ocean. There are strong tidal currents, since the tidal range is so large, and these are believed to have a strong influence on marine life in the area. The Gulf of Carpentaria has also been studied, both for large-scale movement and for tidal flow, to help understand the biology and migration of the important prawns in the area. It has been suggested that the prawns are cunning enough to dig into the bottom when the tidal current is unfavourable, emerging later to hitch a ride in the direction they want to go!

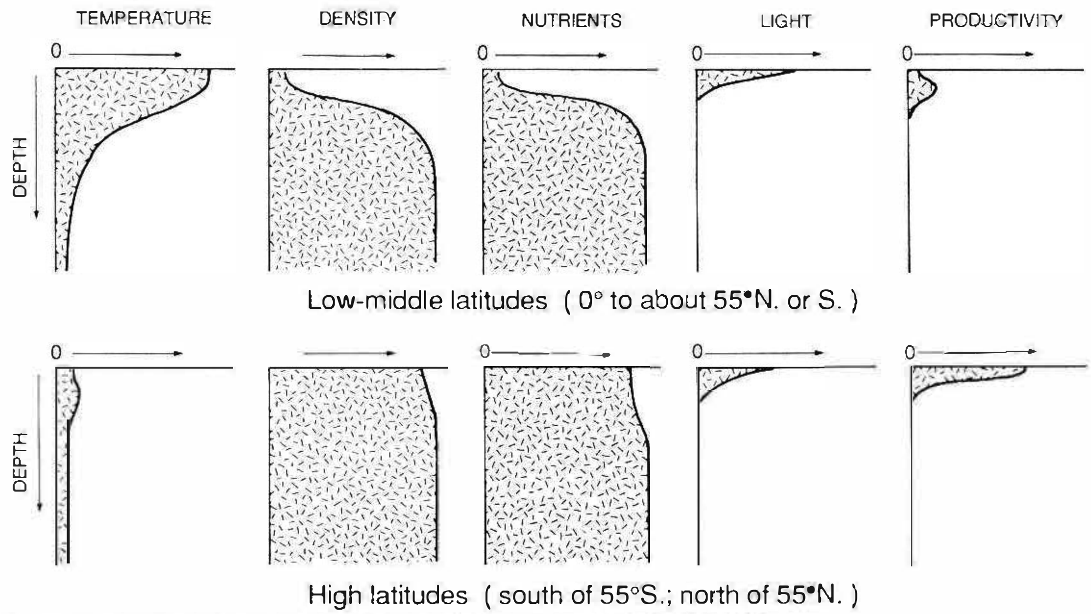

Figure 5. *This figure shows many features of the ocean that are important for living things.*

The upper panel shows the conditions in low and middle latitudes, and the lower panel shows how these conditions differ in high latitudes. For Australia, the upper panel represents the conditions 'near land', from the tropics to southern Tasmania. The lower panel applies near Antarctica. There is, of course, no sudden boundary between the two. Let us look first at the lower half of both panels. The deep water, wherever it is, is cold, high in density, and rich in the nutrients (phosphates, nitrates) needed for plant growth. It is dark, and for this reason productivity (the rate at which microscopic plants grow) is zero. Nearer the surface we find large differences between the two panels. In the upper panel (low to middle latitudes) temperature is high near the surface, and often nearly uniform in the upper few tens of metres, due to mixing by waves. Since density is mainly determined by temperature (the effects of salinity can be ignored for the present), we find the surface density is low. This means the ocean is vertically stable in these low to middle latitudes — it is difficult to mix the water vertically. This stability is very important, since it prevents the rich supply of nutrients in the deeper layers from getting up into the top hundred metres where there is enough light for plants to grow. So we find low nutrients and low productivity near the surface — effectively desert conditions, if one can use such a term. This condition applies for most of the surface areas of the world's oceans. Compare now the conditions at high latitudes. There is little change in temperature or density with depth, so the vertical stability is much less. With help from the stormy weather, it is much easier for the abundant nutrients of the deeper layers to come to the surface. The light is still abundant specially in summer, so productivity is high in near surface layers in these high latitudes. The rapid growth of plants here means there is plenty of food for the zooplankton, and in turn for other animals further up the food chain, including whales and birds. The presence of currents or eddies adds only some embroidery to the above general picture — they will affect the detailed shapes of curves, but not their main features. Upwelling can alter the picture locally by bringing rich waters nearer the surface, and is very important in some parts of the temperate oceans, but it is seldom important near Australia.

The East Australian Current manifests itself as a southerly flow near the edge of the continental shelf, between about Mackay and Jervis Bay. But unlike its Northern Hemisphere counterparts, it is very variable. The current system is better represented as a series of eddies. Since the eddies are almost always anticlockwise, the currents due to them near the shelf edge will be southward, and will be variable. Since most of the shipping has been coastwise, it has encountered only the western edges of the eddies; hence the (variable) southward East Australian Current.

'THE BRINY'

The seas contain about 3.5 per cent of salt. Most of it is common salt (sodium chloride), but many other elements and ions are present in appreciable amounts, and some (magnesium and bromine) are extracted commercially.

The salt has come from the weathering of rocks and from the gasses and liquids that escape from deep in the earth in volcanic regions. Some of the chemicals introduced in these ways have been modified within the oceans, and find their way into sediments, so the detailed history of salt in the sea is complex and not well understood.

Oceanographers have found that the relative proportions of the different ions in sea water are remarkably constant, so that the changes in salt content (salinity) found in the ocean can be thought of as due to the addition or loss of fresh water from an otherwise well-mixed world-wide ocean. Losses are due to evaporation and to formation of sea ice, and additions are due to rainfall and river discharge.

The range in salinity in the oceans is very narrow. Except close to river mouths, the range of salinity is 3.3 to 3.7 per cent, and more than nine-tenths of the volume of the ocean has salinities in an even narrower range — about 3.44 to 3.5 per cent. This very narrow range means that precise measurements are necessary if the small changes in salinity are to reveal themselves. Using modern instruments based on electrical conductivity it is possible to separate samples whose salinities differ by only .0003 per cent. Some of these instruments were developed in Australia.

Salinity is one of the few conservative properties of sea water, since it is not changed by marine organisms or by geological or geochemical processes, at least not within the time scale of mixing in the major ocean basins (1 000 years or so). It is therefore one of the most important tracers that can be used to work out where water has come from. For example, the salinity of the waters around Australia goes through a minimum at depths around 600–1 000 m. Study of this minimum at different places shows that the waters at such depths originate from the surface water found well to the south of Australia, at about 50–55°S.

THE STABLE OCEAN

We might think that storms would keep the ocean well stirred up, but their effects are confined to a shallow surface layer. Even the most severe storm has little effect below about 70 m depth. So the seas everywhere, except near the polar regions, turn out to be markedly layered or stratified, with warm water near the surface and colder water as you go down (Fig. 5). If all the waters in the world's seas were suddenly stirred up, the water temperature would be a chilly 3.5°C.

This layering has very important results, especially for marine life. The 'food chains' in the sea start with minute floating plants, which get their energy from sunlight, and which need nutrients (nitrates, phosphates). There are abundant nutrients in the deeper cold waters, but plants cannot use them because there is no light. In the warmer near-surface layers the plants can grow, but soon use up the available nutrients, so that growth slows down and productivity is limited.

In some parts of the ocean, persistent winds move the nutrient-poor surface waters away from coasts, allowing deeper nutrient-rich water to come nearer the surface — a process called 'upwelling'. The combination of light and nutrient leads to abundant growth of the tiny plants on which marine animals feed, so that upwelling areas are highly productive. The best-known upwelling area is off Peru.

Near-shore Australian waters tend to have only small concentrations of nutrients, and we have no major upwelling areas. We do not know why this is so, because the wind systems should favour upwelling in some areas. The only upwelling areas we know about are off the north coast of New South Wales, off Gippsland and at the western end of Bass Strait. In these areas upwelling is sporadic, intermittent and short-lived. Its influence on productivity is not known. The low level of nutrients and absence of major upwelling areas are factors contributing to the very low position of Australia as a fishing country.

ACKNOWLEDGMENT

Adapted from Chapter 1, which I wrote, in 'Australia's Underwater Wilderness' (Ed. Roland Hughes) 1985, 264 pp. with permission of the publishers (Weldons Pty Ltd: Sydney).

FURTHER READING

For more detail on the physics of the ocean, see:

Pickard, G. L. and Emery, W. J. (1982) 'Descriptive Physical Oceanography'. Fourth Edition, (Pergamon Press: Oxford.)

A local book, with some local examples and a different approach to the subject is:

Beer, T. (1983) 'Environmental Oceanography.' (Pergamon Press: Oxford.)

The Annual Reports and Research Reports of CSIRO Marine Laboratories, Hobart, (formerly CSIRO Division of Fisheries and Oceanography), and of Australian Institute of Marine Science (Townsville), contain semi-popular accounts of their work, and lists of their publications. For CSIRO, these reports cover at least 1974–77, 1977–79, 1979–81, 1981–84 and 1985–87.

CSIRO has also published the following, as one of its 'Research for Australia' series:

CSIRO (1987) 'Oceanography' (CSIRO: Canberra.)

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PREDATION OF THE EGGS OF SILVER GULLS BY REPTILES

The protracted period of laying shown by Silver Gulls *Larus novaehollandiae* near Perth, Western Australia, may be due, in part, to sustained predation of eggs by King's Skinks *Egernia kingii* (Wooller and Dunlop 1979). These large lizards, which average 220 g in weight and have a head width of about 50 mm (Arena 1986), are common on both Penguin Island (32°18′S, 115°42′E) and Carnac Island (32°07′S, 115°39′E) which are the two largest breeding colonies of Silver Gulls on the west coast with about 3 000 and 4 000 breeding pairs respectively (Dunlop and Storr 1981; Dunlop *et al.* 1988). On Penguin Island, Arena (1986) estimated an average density of about 100 skinks per hectare over the whole 12 ha island, with densities up to 800 ha^{-1} in some areas; similar lizard densities probably occur on Carnac Island. The contribution of these lizards to egg losses was assessed on Carnac Island during 1980 by excluding them from part of the laying area.

METHODS

On Carnac Island, Silver Gulls lay in all months from March to November, often with peaks in April and August (Wooller and Dunlop 1979). In March, before laying started, a temporary fence was constructed around a 0.2 ha area containing about 150 nests. The 1 m high fence was of aluminium flywire mesh secured to wooden posts, with its lower section buried in the ground. Skinks within the fence were caught using box traps and by hand, and were relocated over 200 m away. Despite intensive trapping effort, at least one skink was known to have been inside the enclosure during the April laying period. Tiger snakes *Notechis scutatus* present on the island may also take eggs but none were believed to be present inside the enclosure. The fence was removed after the eggs laid in April/May had hatched and before the second major period of laying later in the year.

An unfenced control area was established on another part of the island. This plot was similar to the experimental area in size, shape, substrate, vegetation and the density of the gull nests and skinks. Laying started, ended and peaked simultaneously in both areas, which contained similar proportions of established breeding gulls. All nests in both study areas were marked individually and their contents recorded throughout the year.