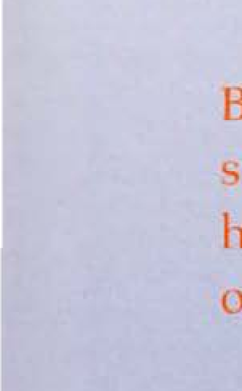
Ocean patterns link life in

the deep

Bryony Bennett explains how studies of an 'ancient mariner' have deepened our knowledge of life in the sea.

Scientists have known for some time that the composition of marine communities in the ocean's upper depths (to ~200 metres) is linked to global and local patterns of water circulation. Whether this applies to species living deeper down in the ocean, however, is a matter of scientific debate.



A supporter of the theory of a link between ocean circulation and deep-sea species is Dr Tony Koslow from CSIRO's Division of Fisheries at Hobart. Koslow's contribution to the debate is founded on an intensive study into orange roughy (deep sea perch) populations off Australia's south-east coast. The study, begun in 1987, yielded valuable information about the structure and function of mid-slope marine communities (700-1200 m deep).

Marine fauna that inhabits deep-water zones of the ocean differs from that living nearer the surface. This is largely because light, temperature and food availability become less favourable as distance from the ocean surface increases.

Past studies have concentrated on these depth-related factors in explaining the composition of species in deep-water environments. This approach, ignoring the influence of ocean circulation, has fostered the belief that organisms in the deep sea are distributed at random, rather than living as members of distinct, interactive communities, (such as occurs at upper depths and on land).

In contrast, Koslow's research indicates that communities do exist in the deep-water zone and that their boundaries are defined, not only by depth, but also by the prevailing oceanic circulation.

Koslow's argument stems from two lines of investigation. First came joint research by the Division of Fisheries and the University of Tasmania into the biology of the orange roughy.

Demersal (bottom) trawl surveys were conducted at mid-slope depths off the coast of south-east Australia. The surveys, to assess the distribution and abundance of orange roughy, also provided information about the abundance, species composition and spatial distribution of mid-slope demersal fishes in the region.

The work revealed a fascinating picture of the roughy's unusually long life cycle: orange roughy mature at about 30 years of age and live to well over 100. It also found that only 2-5% of the roughy's diet was supplied from the water column above (see story p32). For the scientists, this was a clue that the orange roughy belonged to a deep-water community whose survival was linked to the lateral movement of a distinct water mass.

Koslow's second approach involved using his knowledge of the roughy's environment to take a fresh look at the question of species composition in the temperate deep-water zone. He gathered data from marine fauna surveys in the Northern Hemisphere, and analysed it in conjunction with survey results from the Australian roughy community.

Understanding the nature of the water mass that accommodates the orange roughy's deep-sea community is central to appreciating the conclusions that were drawn.

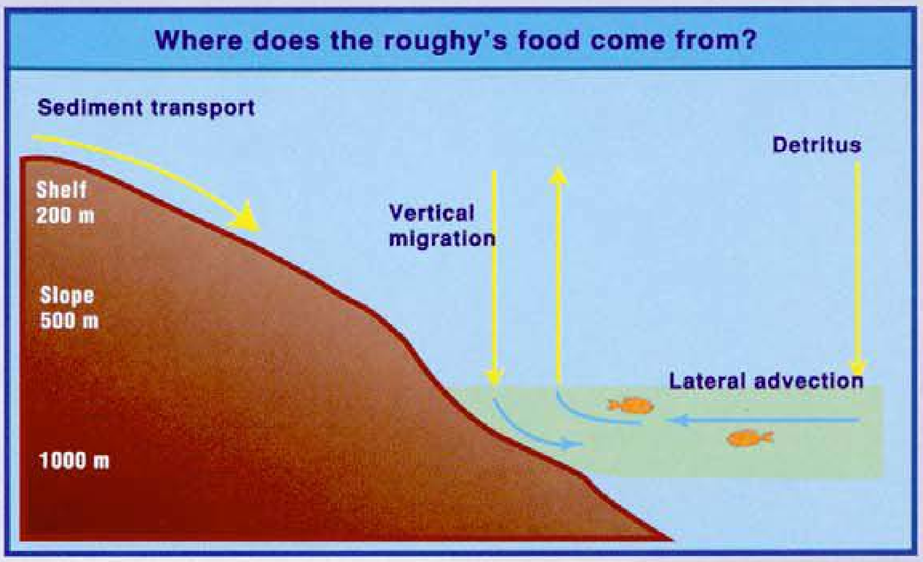
Masses of water

The world's oceans are made up of distinct, layered water masses defined by characteristic temperatures and salt concentrations.

Solving an age-old problem

Commercial-scale stocks of orange roughy (*Hoplostethus atlanticus*) were first discovered 12 years ago in New Zealand waters. In the late 1980s, a major roughy fishery developed along the mid-continental slope at depths of 700-1200 metres off south-eastern Australia. It is Australia's most valuable finfish fishery, worth $30 million a year. It is also one of the deepest fisheries in the world.

The extreme depth of the orange roughy's habitat presented Dr Tony Koslow with a special challenge. Most commercial fishing takes place on the continental shelf which extends down to about 200 m. In terms of nutrients and biomass, this is the richest part of the ocean and its ecology is reasonably well understood. Less is known about the nutrient pathways that sustain deep-water communities.



Only 2-5% of the orange roughy's diet comes from the water column above. Scientists speculate that the remainder is supplied by the Atlantic Intermediate Water mass as it brushes against the continental slope, carrying with it a variety of drifting mid-water creatures.

Koslow and his team at the CSIRO Division of Fisheries have found that orange roughy differ greatly from most species caught for human food consumption. Roughy mature at about 32 years of age, by which time they measure about 32 centimetres (see 'Methulselah of the deep', *Ecos* 68). Older fish, ranging in size from 38 to 45 cm, live to 100 years or more.

The productivity of such slow-growing fish is markedly lower than that of commonly-fished species such as mackeral or tuna, so their long-term sustainable yield will be correspondingly lower as well. An appreciation of the roughy's feeding habits in comparison to fishes that inhabit the ocean's near-surface waters is important to understanding the factors influencing the roughy's extraordinary life cycle.

Picture the response when food is sprinkled into a fish tank: the fish head straight for the surface, open-mouthed in readiness. The food that isn't snapped up in the first flurry sinks slowly, to be grazed later from the bottom.

This process, though many times more complex, also occurs in the ocean. Here life begins with the synthesis of carbohydrates by phytoplankton in the lighted surface layers of the open water (the euphotic zone). These microscopic plant cells are then eaten by herbivorous zooplankton, which in turn support a succession of actively-swimming (nektonic) predators.

Most of the predators that live above about 600 m swim near to the surface at night to feed. One example is the blue grenadier and its prey, which live several hundred metres above the orange roughy. This nocturnal behaviour lets them enjoy the best of two worlds: cropping the richer food developing in the surface layers and avoiding predation by remaining always in the dark. The diet of the blue grenadier community is therefore directly tied to surface productivity.

Organisms living beneath this level, such as the orange roughy, tend not to perform this vertical migration. They are generally thought to rely instead on a constant 'rain' of detritis (plant life and faecal pellets) that floats down from the ocean's upper layers.

This kind of diet is like eating 'crumbs from the table', Koslow says. He and fellow scientist Cathy Bulman examined the diet of nearly 7500 fish from south-eastern Australian waters caught during trawl surveys in 1988 and 1989. Their work has shown that the orange roughy is not accustomed to such a meagre existence.

On a proportional basis, roughy appear to eat almost twice as much as other fish of the deep (about 1% of their body weight daily). Most deep-water fish have a low metabolic rate: often 10 to 100 times less than that of surface species. This is partly an adaptation to the fact that food is difficult to come by at depth, because light for plant growth is non-existent.

Deep-dwelling fish generally float with the prevailing currents in open water, swimming slowly if at all. They have a high water content and little muscle. In contrast, orange roughy, with their well-developed musculature, aggregate around sea mounts (small hills) in areas with high currents sweeping over the ocean bottom. They must exert themselves to maintain their position against the current, although they appear to take advantage of areas of low currents in the lee of the sea mounts. Consequently abundant stocks can only occur where there are high inputs of food.

The area of the continental slope inhabited by orange roughy follows a narrow band around south-eastern Australia. The slope is steep so does not cover much area. Scientists can calculate how much plant production occurs on the surface and how much makes its way down to the 700-1200 m zone.

Using this data, and their knowledge of the fish's metabolism, Bulman and Koslow calculated that only 2-5% of the roughy's diet could be supplied from the water column above. Where else could it come from? (See main story)

These water masses originate in distinct and usually extreme parts of the ocean. For example, the coldest and densest water, which flows along most of the world's sea floor, originates in winter off Antarctica. Above that typically flows the Deep Water at 2000-3000 m, which is formed in winter in the far North Atlantic.

Of particular interest to Koslow was the water mass that originates at about 50-55°S latitude in the vicinity of the Antarctic Polar Front. Here, two bodies of water arriving from different directions meet and mix (see diagram).

Moving north from the continent itself is a thin surface layer of cold water (about 0°C), heavily diluted by melting sea ice. North of the Polar Front is the Subantarctic Upper Water, which occupies the upper 500 m of the water column and ranges from 4-15°C in winter.

When these waters merge, the mixture sinks to about 700-1200 m and begins to spread around the northern rim of the Southern Ocean as the Antarctic Intermediate Water, so-called because it occupies an intermediate position between the ocean's near-surface and deeper water masses. The mid-slope fish community off south-eastern Australia, home of the orange roughy, resides in this distinct water mass.

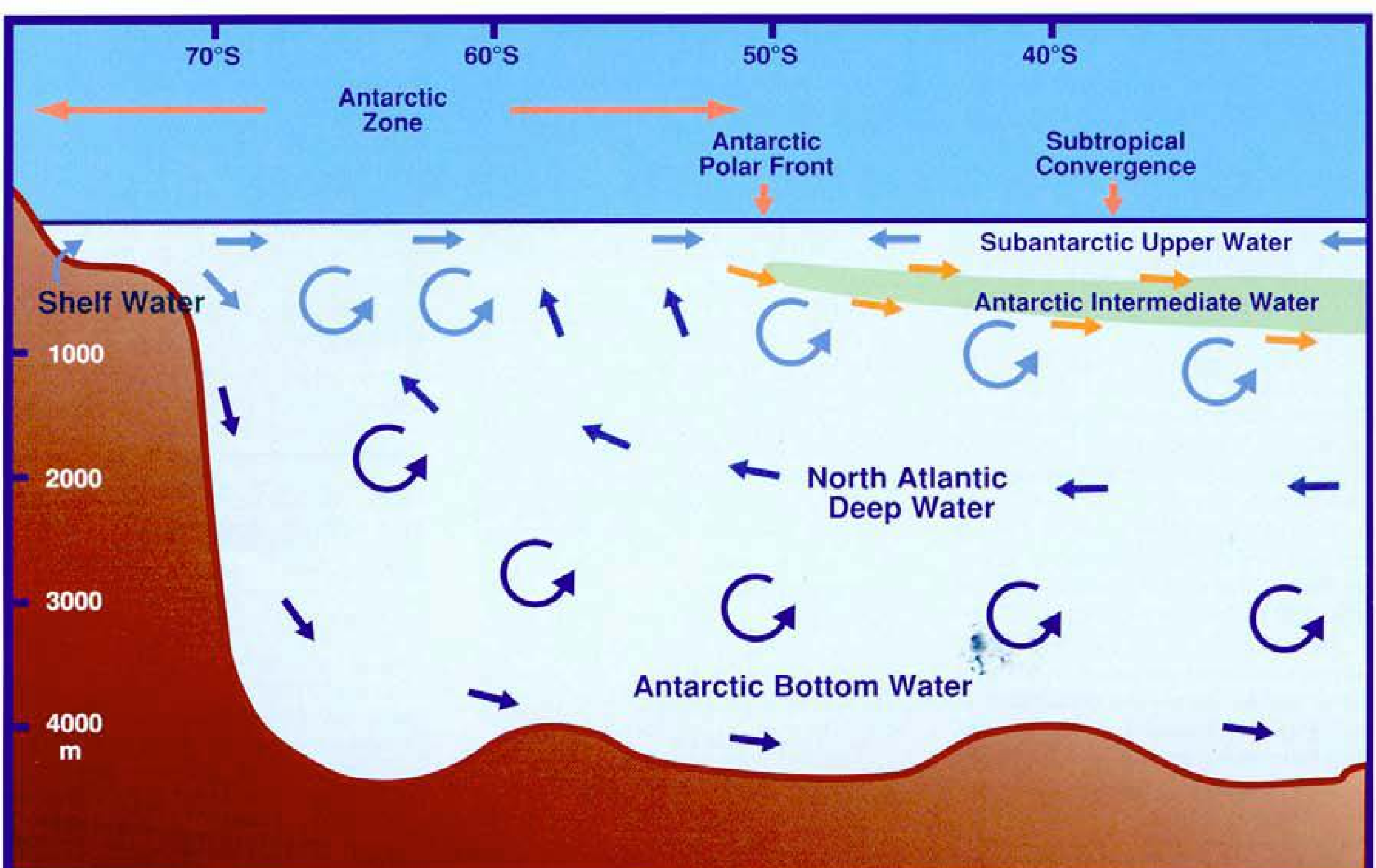
Antarctic Intermediate Water can be clearly traced as a tongue of relatively low-saline water to about 20°N into the Atlantic Ocean, but it does not seem to penetrate the North Pacific. This characteristic makes the water mass useful to the study of whether deep-sea communities identified on a local scale persist over a greater range in accordance with ocean circulation.

Koslow reasoned that if species composition in the temperate, mid-slope region were non-random and were regulated by water circulation, there would be:

- a stronger affinity of the south-east Australian fauna with the North Atlantic than with the North Pacific fauna;
- different faunas between the middle and upper slope off south-eastern Australia, consistent with depth-related changes in water mass composition; and
- strong affinities among the mid-slope faunas of south-eastern Australia, the Great Australian Bight and New Zealand, a region linked by circulation of Antarctic Intermediate Water.

To test these predictions, Koslow gathered records of the total families, genera and species, and of the dominant species of mid-slope communities, at eight different oceanic regions. These included areas of south-eastern Australia, the Great Australian Bight, Challenger Plateau west of New Zealand, Chatham Rise (east of New Zealand), the north-east and north-west Atlantic and the north-east and north-west Pacific.

Analysis of the data revealed between 16 and 20 (76-95%) of the 21 dominant species in common at the relatively close locations of the Great



Vertical components of water circulation in the Atlantic sector of the Southern Ocean. Antarctic Intermediate Water, home of the orange roughy, exists between the ocean's near-surface and deeper water masses. This water mass originates when two bodies of water arriving from different directions meet and mix. Antarctic Intermediate Water extends to about 20°N into the Atlantic Ocean, but does not seem to reach the North Pacific. This characteristic makes the water mass useful to the study of whether deep-sea communities identified on a local scale persist over a greater range in accordance with ocean circulation.

Above: Dr Tony Koslow: studying life in the deep sea. Left: Surveys of deep-sea communities of south-eastern Australia revealed a fascinating picture of the orange roughy's unusual life cycle and feeding habits. This was a clue that the roughy belonged to a community whose survival was linked to a distinct water mass.

Australian Bight, Challenger Plateau and Chatham Rise. The fauna of this distinct community occupied a province extending at least from the Great Australian Bight to the Chatham Rise, NZ, a distance of about 5000 kilometres.There were five (24%) of the dominant species in the north-east Atlantic and two (10%) in the north-west Atlantic. None of these dominant species were observed in surveys of the Pacific.

A similar pattern emerged at the family level. Of the 37 families of fish associated with the mid-slope zone off south-east Australia, 16-21 were found in the North Atlantic, but only eight in the North Pacific.

The analysis also revealed distinct communities of demersal fish at upper (to 500 m) and mid-slope (800-1200 m) depths off south-east Australia.

According to Koslow, these biogeographical patterns appeared consistent with oceanic circulation at mid-slope depths. At the species level, the mid-slope demersal fish fauna of temperate Australia and New Zealand links with the temperate North Atlantic fauna, but not the North Pacific, consistent with the circulation of intermediate water masses between ocean basins.

The results confirmed Koslow's belief that water exchange around the Southern Ocean, and between the Southern Ocean and the North Atlantic (in particular due to the flow of the Antarctic Intermediate Water) has led to biogeographical links among these areas. On the other hand, mid-slope depths in the North Pacific, which produces its own intermediate water that does not circulate to other ocean basins, appear biologically isolated from other such regions of the world's oceans.

Koslow re-examined studies of deepwater fish from around the North Atlantic basin, from off North Africa, Europe, Canada, the United States and the Caribbean. Again there was consistency between oceanic and fish community structure, presumably based on the influence of ocean currents on the drift and distribution of fish during the early life history. The life history of deepwater fishes – that is, their migrations and vertical distribution through ontogeny (their development) – is likely to have adapted to the physical circulation, so far as necessary to maintain population structure.

Koslow speculates that the deepwater circulation may also explain how large populations of metabolically-active fish, such as orange roughy, can be sustained along the northern rim of the Southern Ocean.

Where the Atlantic Intermediate Water brushes against the continental slope, strong currents are often found that carry past a smorgasboard of drifting mid-water creatures. The orange roughy appear to have adapted by aggregating in canyons and behind seamounts and by making use of other topographic features so that, like the trout in backwaters and eddies, they may conserve energy and prey on the moveable feast that flows past.

But scientists are only beginning to obtain an insight into the major links between ocean circulation and the processes that sustain and structure life in the deep sea.

More about ocean circulation and orange roughy

Bulman CM & Koslow JA (1992) Diet and food consumption of a deep-sea fish, orange roughy *Hoplostethus atlanticus* (Pisces: Trachichthyidae), off south-eastern Australia. *Marine Ecology Progress Series* **82**: 115-129.

Koslow JA (1993) Community Structure in North Atlantic deep-sea fishes. *Progress in Oceanography* **31**: 321-338.

Koslow JA Bulman CM & Lyle JM (1994) The mid-slope demersal fish community of south-eastern Australia. *Deep Sea Research* **41**: 113-141.

Haedrich RL & Merrett NR (1990) Little evidence for faunal zonation or communities in deep-sea demersal fish faunas. *Progress in Oceanography* **24**: 239-250.

Beckmann R (1991) Methuselah of the deep. *Ecos* **68**: 13-17.