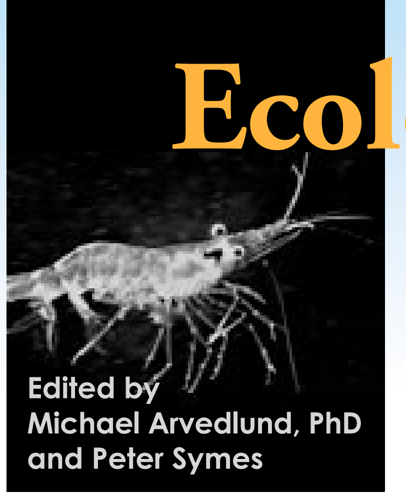

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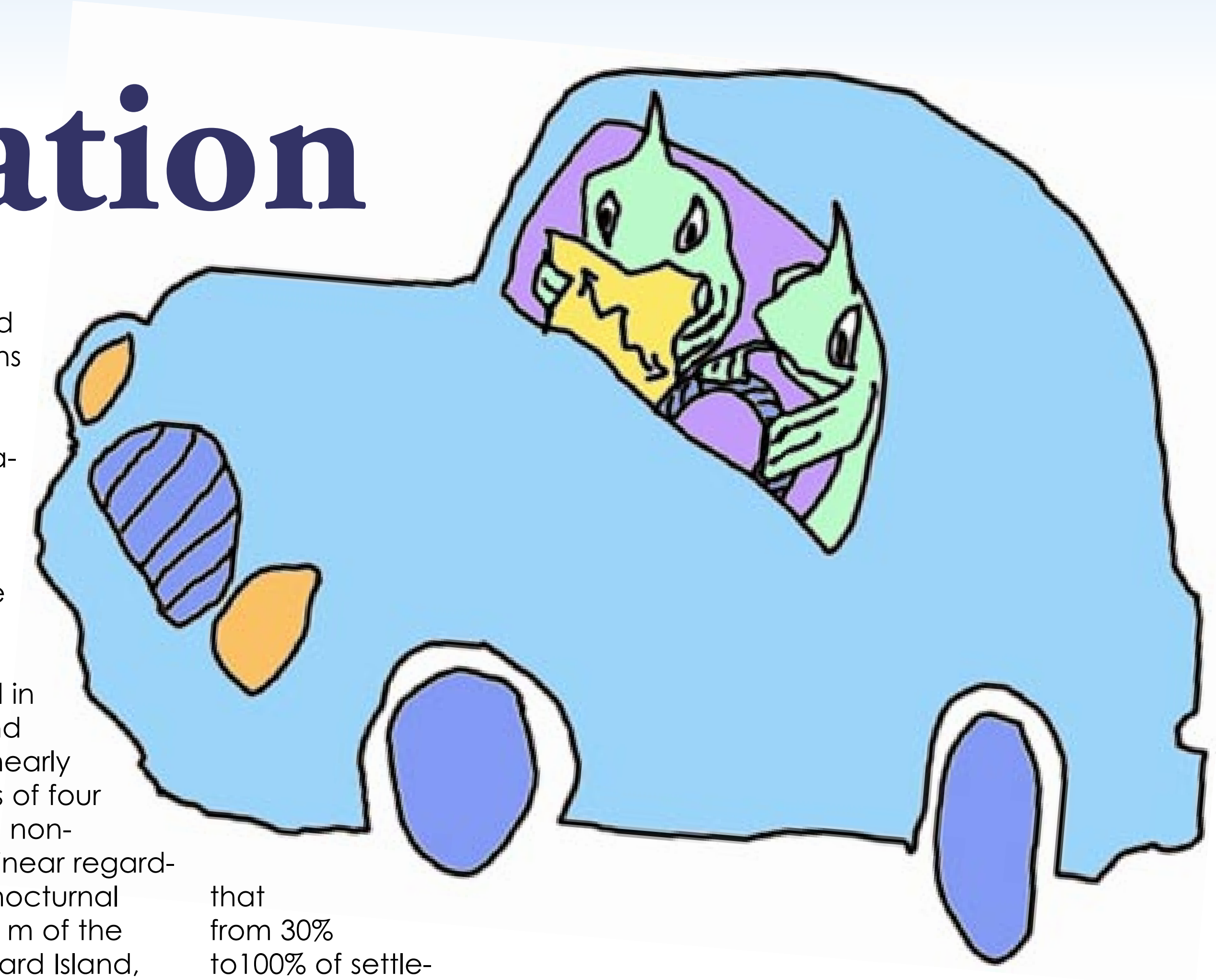
ILLUSTRATIONS BY GUNILD AND PETER SYMES

Coral Reef Fish Larvae

Masters of Navigation



Coral reef fishes have a life cycle that is divided in two. They begin their life after hatching with a pelagic larval phase, lasting from a week up to two months depending on the species, and ends with a benthic phase, when the fish larvae settles to the coral reef one night. For decades the pelagic phase has been a black box to researchers. Only recently has the lid to this black box been opened.

In a recent article in X-RAY MAG, we looked at the astonishing swimming ability reef fish larvae have. However, long distance swimming is of little use without navigation. Orientation is necessary if a pelagic reef fish larva is to find a reef by other than chance, and orientation requires not only cues and the sensory means to detect a coral reef, but also the ability to determine the direction from which the cues originate. Recent research has shown that the swimming behavior of reef fish larvae on the open ocean indicates that they do orientate rather than just cruise about haphazardly. But exactly what cues reef fish may detect and use is not so obvious.

The well-known coral reef fish researcher Dr Jeff Leis, the Australian Museum, have in recent years caught, identified, and then followed released reef fish larvae off shore in many research projects, determining direction and swimming speed of reef fish larvae.

Some reef fish larvae swim away from the reef, out of sight of it, and then return. This behavior implies either a good memory for reef location, or the aptitude to detect a reef tenuously and return to it. For example at Lizard Island, the northeastern Great Barrier Reef, Dr Leis and his research team analyzed the swimming directions of a group of fish larvae of several coral reef fish species, each released individually, and showed that individual swimming patterns of most were not random but significantly towards one particular direction, and that on average, these swimming patterns differed among three locations on different sides of the island, and were offshore at each location. This implied that the fish larvae – all less than a few centimeters - could sense the Lizard Island from over 1 km offshore.

Recent research has shown that the swimming behavior of reef fish larvae on the open ocean indicates that they do orientate rather than just cruise about haphazardly

At an oceanic atoll in the Pacific, Dr Leis and his team found that nearly all swimming patterns of four reef fish species were non-random and usually linear regardless of location. In a nocturnal experiment, within 50 m of the coral reefs, also of Lizard Island, the Australian researchers Dr Stobutzki and Dr Bellwood could show that the majority of fish larvae swam toward the nearest reef indicating they knew the way to the reef.

Settlement

The transition from the pelagic (open water) environment to a reef, i.e. the settlement, is complex. Reef-fish larvae are highly selective about where they settle. Dr Leis and his team also found that from 30% to100% of settlement-competent larvae of a given species may reject a given reef and swim back into open water.

For example, some species will settle only on lagoonal reefs, whereas others reject shallow lagoon reefs, but accept deeper ones. Once over a reef, selectivity about settlement sites can also be great: some species only settle on live coral, whereas others only settle into schools of similarly-sized recent recruited, now juvenile reef fish. So ready-to-settle fish larvae certainly do not simply settle onto the first reef they bump into.

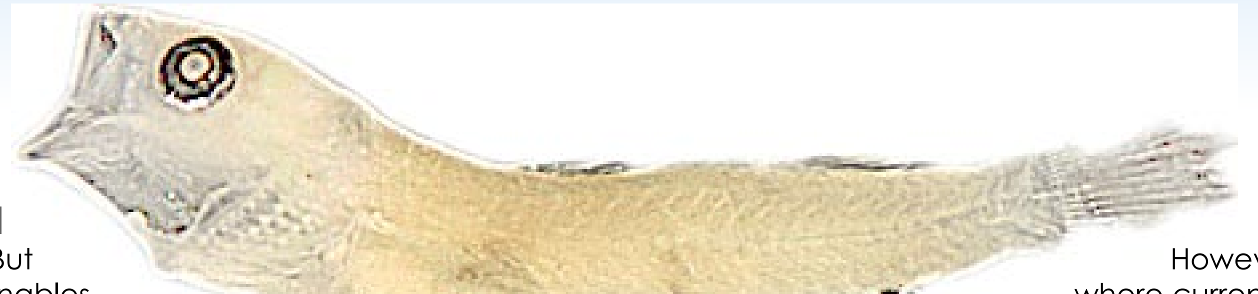
The above research on settlement behaviour was done during the day, and we have no idea how settlement behaviour might differ at night.

The combination of habitat selectivity and swimming abilities means that settlement-competent reef-fish larvae have the potential to actively examine a variety of reefs at scales of tens of kilometers to find a suitable settlement site.

But as Dr Leis expressed the situation for researchers studying the interesting life of reef fish lar-

ecology

Larval Navigation



LEFT: Goby larva, *Psilotris batrachodes*, 6 mm. Photo courtesy of Dr Benjamin Victor. **www.coralreeffish.com**

vae, "*matters are yet even more complex.*" Behaviour also varies within a species depending on the situation. For example, larvae of a number of species released nearby to reefs swam much slower when approaching the reef than if they swam away from it, and larvae of one damselfish consistently swam faster in open water in an atoll lagoon than in ocean waters surrounding the atoll.

Vertical distribution

Vertical distributions can also differ between locations. For example, fish larvae may swim deeper in the ocean than in an atoll lagoon, or they may swim deeper off the windward than off the leeward side of a reef. We can expect that behaviour differs between night and day and probably at different stages in larvae development. This kind of behavioural flexibility further complicates any attempts to make realistic mathematical model dispersal – models which are very popular among researchers, because they may be an important tool in e.g. coral reef park management and fisheries management. However, it is of course necessary for these models to be based on correct assumptions.

Sensational Senses

But what senses enables minute reef fish larvae to navigate in such astonishing complex ways and over several kilometres? Dr Leis suggests that many possible cues associated with reefs could provide clues for navigation. These include smells and sound which comes from reefs; differences in wind- or wave-induced turbulence; gradients in abundance of fish, plankton, or reef detritus; and differences in temperatures of lagoonal or reef flat water flowing from a reef. In some cases, a magnetic compass or sun compass could help in increasing chances of fish larvae encountering a reef (e.g., a larva in the Coral Sea would increase its chances of encountering one of the reefs on the Great Barrier Reef by swimming to the west), but it seems unlikely either could assist orientation toward a particular reef.

One possible exception is that a magnetic sense could allow a fish larva to detect an oceanic basalt island (or, some volcanic islands on continental plates) on which reefs were growing, because basalt islands have a magnetic anomaly.

Although fish can sense via the lateral line that they are moving through water when they are swimming, unless they have an external reference, such as a view of the bottom, they will be unable to determine that they are being moved by and with the water, as when being carried along with a current. Therefore, currents are potentially detectable using vision near the bottom or near a reef, but it is unlikely that currents or movement by them will be detectable in blue water, i.e. offshore, and thus they are unlikely to be an aid to orientation.

Some of these possibilities seem intrinsically more general and therefore more likely in a evolutionary sense to have been utilized. For example, sound is almost current independent, travels in all directions from the source, and spreads over long distances, so it could be a very general cue.

Smell

In contrast, smells are current dependent, must travel with water movement, and would be of little use "up-current" of any reef. However, where currents are weak, each reef might be surrounded by a diffusion-maintained "halo" of smell that could provide cues that a reef was near, and a similar halo could be established by current reversals such as those caused by tides.

Electromagnetivity

Magnetic anomalies are current independent, and more likely to be associated with reefs on oceanic islands than with continental-shelf reefs. Most reef fish species have wide distributions i.e. they live on a variety of island and shelf habitats, and in a variety of current regimes that differ in their predictability over many scales. In addition, changes in sea level over time can result in radical changes in reef systems and associated currents. Therefore, it seems likely that any cues to which reef fish larvae have become adapted to use in finding reefs would be general ones, useful over much or all of the range of the species.

However all these predictions based on theoretical arguments should be treated with caution until they can be tested with reef fish larvae. Reef fish researchers have been misled by similar theory-based predictions in the past.

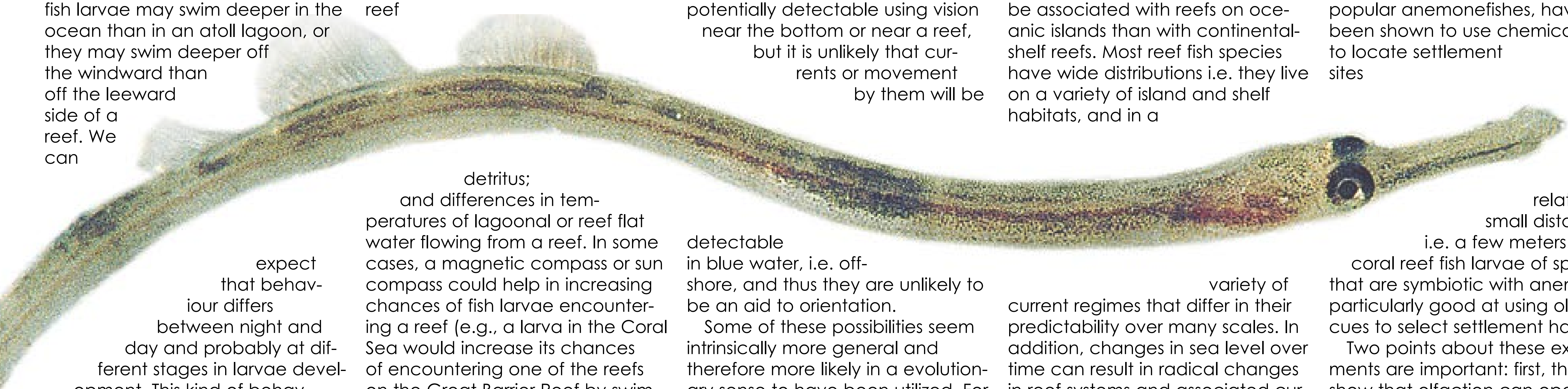
Owing to Oders

Olfaction has the potential to operate over larger scales, as has been known with salmons for many years. If odors are carried by currents and structured by fronts between water masses, olfaction operating at a small scale could result in orientation over larger scales.

This may also be the case with temperature differences. Damselfishes, among them the popular anemonefishes, have been shown to use chemical cues to locate settlement sites over relatively small distances, i.e. a few meters. Are coral reef fish larvae of species that are symbiotic with anemones particularly good at using olfactory cues to select settlement habitat?

Two points about these experiments are important: first, they show that olfaction can operate over scales of up to a few tens of meters - perhaps even much longer distances; second, they were done over the reef habitat.

We do not know yet if olfaction can be used in the pelagic environment in the find reefs. Olfaction is clearly important in the location of specialized habitats such as anemones or corals, and in the location of conspecifics all over



INSET: Juvenile pipefish. Photo: Peter Symes

Larval Navigation

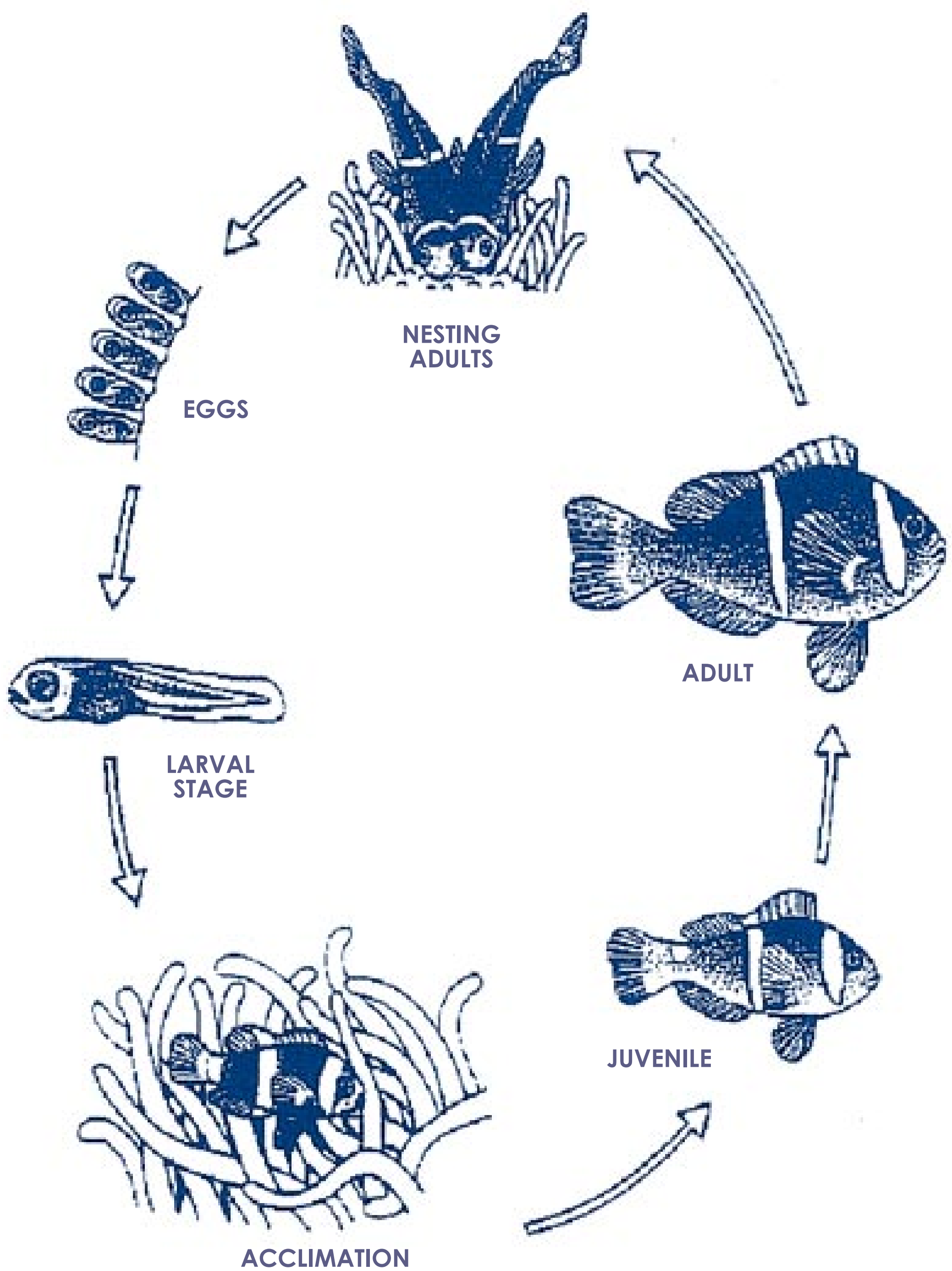


ILLUSTRATION COURTESY OF FAUTIN AND ALLEN 1997

Figure 1. Coral reef fish life cycle, exemplified by an anemonefish

small scales within reef habitats.

Use of olfaction for orientation by other than a few species of pomacentrids, or over larger scales, or in the pelagic environment, is a real possibility given the results to date, but this has not yet been demonstrated by reef fish researchers.

Sound

Reefs are noisy places and sound has the potential to provide orientation cues over a wide range of scales. The lateral line is sensitive to water movement, but is capable of detecting this over only small distances, on the order of 1–3 body lengths. Vision is used by many reef fish larvae on short distances, i.e. less than 50 m and even at night in dim light. A magnetic sense could potentially operate over a variety of scales, from very large (oceanic), as has been shown is the fact for some species of tunas and salmon, to relatively small (local), as shown in hammerhead sharks. It is likely that different cues are used at different scales even by a single individual: a possible scenario is use of sound to locate the reef, vision and the lateral line to avoid predators near the reef, smell to locate the settlement habitat, and vision to locate the settlement site in the habitat.

Sound has proven one to be a cue used by some reef fish larvae. By playing bio sounds from the reef, i.e. sounds from snapping shrimps, fish grazing and fish making sounds with the swim bladder, from underwater speakers next to light traps, which are known to attract many reef fish larvae, and then compare with light traps without bio sounds, Dr Leis and several other researchers have shown that reef bio sounds provide useable cues for settlement-stage larvae searching for settlement sites.

Conclusion

As with the olfactory cues, many details remain to be determined, including when in the development the ability to hear and use sound for navigation develops, and what sounds (frequencies and intensities) larvae can hear and use, and over what scales. It is, however, clear that sound and chemical cues can be an important orientation and navigation cue for larval reef fishes in both temperate and coral-reef environments.

Summed up, aside from olfaction, hearing, and vision, none of all these cues mentioned has yet been shown to be used by reef fish larvae for orientation, and even with these, the use has been at either relatively small or unknown scales. However, based on our current knowledge of the very complex biology of reef fish larvae, researchers are looking forward to conduct many more experiments with these fascinating creatures. It is certain that they have yet many more surprises waiting for us. It is a research area only in its very beginning.

RIGHT: Albacore larva, *Thunnus albacares*, 5.2 mm. Photo courtesy of Dr Benjamin Victor.
www.coralreeffish.com

Literature

This text has mainly been based on: Leis, J.M. & McCormick, M.I. 2002. The biology, behavior, and ecology of the pelagic larval stage of coral reef fishes. In: Coral reef fishes. Dynamics and diversity in a complex ecosystem (ed. P.F. Sale) San Diego & London: Academic Press p 171–199.

Figure one is from Fautin, D.G. & Allen, G.R., 1997. Field guide to anemonefishes and their host sea anemones. 2nd edn. Perth, Australia: Western Australian Museum. A free electronic version is available from this website: **http://biodiversity.uno.edu/ebooks/intro.html** ■