Ocean acidification impairs olfactory discrimination and homing ability of a marine fish

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The persistence of most coastal marine species depends on larvae finding suitable adult habitat at the end of an offshore dispersive stage that can last weeks or months. We tested the effects that ocean acidification from elevated levels of atmospheric carbon dioxide (CO_2) could have on the ability of larvae to detect olfactory cues from adult habitats. Larval clownfish reared in control seawater (pH 8.15) discriminated between a range of cues that could help them locate reef habitat and suitable settlement sites. This discriminatory ability was disrupted when larvae were reared in conditions simulating CO_2-induced ocean acidification. Larvae became strongly attracted to olfactory stimuli they normally avoided when reared at levels of ocean pH that could occur *ca.* 2100 (pH 7.8) and they no longer responded to any olfactory cues when reared at pH levels (pH 7.6) that might be attained later next century on a business-as-usual carbon-dioxide emissions trajectory. If acidification continues unabated, the impairment of sensory ability will reduce population sustainability of many marine species, with potentially profound consequences for marine diversity.

climate change | larval sensory mechanisms | population connectivity | population replenishment

Ocean acidification caused by the uptake of additional carbon dioxide (CO_2) at the ocean surface is now recognized as a serious threat to marine ecosystems (1–4). At least 30% of the anthropogenic CO_2 released into the atmosphere in the past 200 years has been absorbed by the oceans, causing ocean pH to decline at a rate ≈100 times faster than at any time in the past 650,000 years (1, 4). Global ocean pH is estimated to have dropped by 0.1 units since preindustrial times and is projected to fall another 0.3–0.4 units by 2100 because of existing and future CO_2 emissions (1, 5–6). Considerable research effort has focused on predicting the impact that reduced carbonate-ion saturation states that accompany ocean acidification will have on calcifying marine organisms, particularly corals and other invertebrates that precipitate aragonite skeletons (2–3, 6). However, the effects that ocean acidification will have on other marine organisms, including fishes, remain almost completely unknown, especially for conditions of atmospheric carbon dioxide and seawater pH that could occur in the near future (4, 7–9).

The persistence of most coastal marine species depends on the ability of larvae to locate suitable settlement habitat at the end of a pelagic stage that can last weeks or months. Accumulating evidence for reef fishes suggests that both reef sounds (10) and olfactory cues (11–13) are used by larvae to locate reefs. The olfactory organs of many reef fishes are well-developed by the end of the larval phase (14–15), and it has recently been shown that larvae of some species can discriminate the smell of water from their natal reef compared with water from other reefs (13), which provides a mechanism to explain high levels of self-recruitment in some reef fish populations (16–19). It is well known that coral reef fish larvae can use olfactory cues to identify suitable settlement sites once they are in the vicinity of reef habitat. Settling larvae have been shown to respond to olfactory signals from preferred microhabitats (12, 20), resident conspecifics (21–23), or symbiotic partners such as anemones (24–25). Any disruption to the ability of larvae to detect and discriminate between olfactory cues that guide them to reefs, or that enable them to select preferred settlement habitat, would have far-reaching implications for the sustainability of adult populations.

We tested if elevated CO_2 and reduced seawater pH consistent with ocean acidification predictions could affect the ability of orange clownfish (*Amphiprion percula*; Pomacentridae. Fig. 1) larvae to respond to olfactory cues that are used to locate reef habitat and distinguish preferred settlement sites. Specifically, we tested the ability of settlement-stage larvae to respond to olfactory cues that are preferred during the settlement process compared with olfactory cues that are likely to be avoided when searching for reefs and settlement sites. Orange clownfish mostly live on oceanic reefs surrounding vegetated islands and recent research has shown that the larvae can discriminate between seawater from reefs surrounding vegetated islands versus seawater from reefs without islands (26). Furthermore, the larvae are positively attracted to water-borne cues from tropical rainforest trees (26) that should provide a reliable cue to the presence of vegetated oceanic islands. We tested the response of larval clownfish to olfactory cues from a range of tropical vegetation types when reared in seawater simulating 2 future CO_2-induced acidification scenarios (seawater pH 7.8 and 7.6) compared with current-day controls (pH 8.15). For larvae reared in each treatment we tested preference or avoidance of olfactory cues from the leaves of 3 vegetation types: (*i*) a tropical rainforest tree (*Xanthostemon chrysanthus*) that is a positive cue for settling clownfish (26), (*ii*) a swamp tree (*Melaleuca nervosa*) that contains pungent oils in the leaves and is avoided by settling clownfish (26), and (*iii*) a tropical savannah grass (*Megathyrsus maximus*) that is not expected to provide a reliable cue for the presence of trees on islands.

It is well known that anemonefishes are positively attracted to olfactory cues of host anemones (24–25). Therefore, we also tested the ability of larval clownfishes to respond to anemone olfactory cues when reared at the 3 pH levels. Finally, the presence of adult populations should be a good signal of favorable habitat and previous studies have found that larvae of some reef fishes are attracted to olfactory cues from conspecific adults (21–22). However, in species such as the orange clownfish where many larvae recruit to natal reefs (19), it would also be advantageous for juveniles to be able to discriminate between their parents and other adults to avoid inbreeding that could result

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