RESPONSE OF FISH TO OCEAN WARMING

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According to the IPCC, CO_2-induced global warming will be net harmful to the world's marine species. This summary examines this hypothesis for various fish species, presenting evidence in opposition to the IPCC's point of view.

Noting "effects of climate-driven production change on marine ecosystems and fisheries can be explored using food web models that incorporate ecological interactions such as predation and competition," citing the work of Cury *et al*. (2008), Brown *et al*. (2010)[1] used the output of an ocean general circulation model driven by a "plausible" greenhouse gas emissions scenario (IPCC 2007 scenario A2) to calculate changes in climate over a 50-year time horizon, the results of which were then fed into a suite of models for calculating primary production of lower trophic levels (phytoplankton, macroalgae, seagrass and benthic microalgae), after which the results of the latter set of calculations were used as input to "twelve existing Ecopath with Ecosim (EwE) dynamic marine food web models to describe different Australian marine ecosystems," which protocol ultimately predicted "changes in fishery catch, fishery value, biomass of animals of conservation interest, and indicators of community composition."

The primary production increases suggested by their work to result from future IPCC-envisioned greenhouse gas emissions and their calculated impacts on climate "will provide opportunities to recover overfished fisheries, increase profitability of fisheries and conserve threatened biodiversity," which most would characterize as an important set of temperature-induced benefits.

In discussing their findings, the seventeen scientists state under the IPCC's "plausible climate change scenario, primary production will increase around Australia" with "overall positive linear responses of functional groups to primary production change," and "generally this benefits fisheries catch and value and leads to increased biomass of threatened marine animals such as turtles and sharks," adding that the calculated responses "are robust to the ecosystem type and the complexity of the model used." Given these findings, in the concluding sentence of their paper, Brown *et al*. state the primary production increases suggested by their work to result from future IPCC-envisioned greenhouse gas emissions and their calculated impacts on climate "will provide opportunities to recover overfished fisheries, increase profitability of fisheries and

[1] http://www.co2science.org/articles/V13/N37/B3.php.

conserve threatened biodiversity," which most would characterize as an important set of temperature-induced benefits.

Working with real-world data, Drinkwater (2006)[2] reviewed the status of marine ecosystems of the northern North Atlantic in the early twentieth century during a regime shift, which he defined as "a persistent radical shift in typical levels of abundance or productivity of multiple important components of the marine biological community structure, occurring at multiple trophic levels and on a geographical scale that is at least regional in extent." In doing so, Drinkwater reports "in the 1920s and 1930s, there was a dramatic warming of the air and ocean temperatures in the northern North Atlantic and the high Arctic, with the largest changes occurring north of 60°N," which warming "led to reduced ice cover in the Arctic and subarctic regions and higher sea temperatures," as well as northward shifts of multiple marine ecosystems.

In the realm of biology, the early twentieth century warming of North Atlantic waters "contributed to higher primary and secondary production," in the words of Drinkwater, and "with the reduced extent of ice-covered waters, more open water allow[ed] for higher production than in the colder periods." As a result, cod "spread approximately 1200 km northward along West Greenland," and "migration of 'warmer water' species also changed with earlier arrivals and later departures." In addition, Drinkwater notes "new spawning sites were observed farther north for several species or stocks while for others the relative contribution from northern spawning sites increased." Also, he writes "some southern species of fish that were unknown in northern areas prior to the warming event became occasional, and in some cases, frequent visitors." In considering these findings, it is clear that these marine species were fully able to take advantage of the warming experienced during this era that Drinkwater claims "is considered to constitute the most significant regime shift experienced in the North Atlantic in the 20th century."

In prefacing their work Seo *et al*. (2011)[3] write "Pacific salmon (*Oncorhynchus* spp.) play an important role as both keystone species in North Pacific ecosystems and as an ecosystem service that provides human food resources for countries of the North Pacific rim," citing Kaeriyama (2008); and they note the Hokkaido chum salmon (*O. keta*) experiences a period of critical mortality "is characterized by size-dependent mortality and size-selective predation, immediately after seaward migration," citing the work of Healey (1982), Kaeriyama (1986), Kaeriyama and Ueda (1998) and Kaeriyama *et al*. (2007)." In an effort to determine the effect of global warming on this critical mortality period in the life of Hokkaido chum salmon, Seo *et al*. used multiple regression and path analysis to examine the effects of regional and larger spatial scales of climatic/oceanic conditions on the growth, survival and population dynamics of the species.

Based on their analysis, the three researchers, all of them with the Faculty of Fisheries Sciences at Japan's Hokkaido University, determined growth of one-year-old chum salmon in the Okhotsk Sea "was less during the period from the 1940s to the mid-1970s compared to the

[2] http://www.co2science.org/articles/V9/N14/C2.php.
[3] http://www.co2science.org/articles/V14/N24/B1.php.

period from the mid-1980s to the present," which result "was directly affected by warmer sea surface temperatures associated with global warming." And they add "the increased growth at age one led directly to higher survival rates and indirectly to larger population sizes."

Studying juvenile sockeye salmon (*Oncorhynchus nerka*) in an Alaskan watershed that had experienced a 1.9°C increase in summer water temperature over the prior 46 years, Bentley and Burgner (2011)[4] hypothesized that the warming of the region "would have resulted in a corresponding increase in fish metabolism, and thus potential consumption rates, that would increase infestation rates of the tapeworm *Triaenophorus crassus*." The set of events and their envisioned interaction seemed quite logical, so they proceeded to test their hypothesis by comparing infestation rate data for *T. crassus* collected between 1948 and 1960 with similar data obtained in 2008 and 2009 from the Wood River system of Bristol Bay, Alaska.

In discussing their findings, the two U.S. researchers from the University of Washington's School of Aquatic and Fishery Sciences say in "comparing the average summer air temperature to the parasite prevalence of juvenile sockeye salmon, we found no significant relationship over the fifteen years of collected data." They also report in "evaluating the influence of average summer air temperature on the parasite infestation rates of juvenile sockeye salmon, we again found no significant relationship for either parasite abundance or parasite intensity," further noting "when we compared the 13 years of historic parasite prevalence to equivalent data collected in 2008 and 2009, we did not find a statistically significant positive long-term trend in the data." Moreover, according to Bentley and Burgner, "the parasite abundance of examined sockeye salmon smolts also did not exhibit a statistically significant long-term trend using the eight years of historic data and the two years of contemporary data." Lastly, they write "evaluating the relationship between time and parasite intensity produced similar results as the other five comparisons, with there not being a statistically significant positive relationship." In light of such observations, in the concluding sentence of their paper Bentley and Burgner say their data demonstrate "the complex effects of warming have not summed to generate a measurable change in the infestation rates of juvenile sockeye salmon in the Wood River system."

Also working in Alaska, but focusing on salmon in Auke Creek, a small lake-outlet stream near Juneau, where there have been complete daily counts of all adult pink salmon migrating into the creek since 1971, Kovach *et al*. (2012)[5] set out to use "phenotypic data on migration timing, archived genetic samples and data from a marker locus, the allele frequencies of which were experimentally altered more than 30 years ago, to determine whether change in migration timing in a population of pink salmon has a genetic basis (i.e., microevolution)." In doing so the three researchers determined both even- and odd-year adult pink salmon that spawn in the warming Alaskan stream are migrating into freshwater nearly two weeks earlier than they did 40 years ago. They also found experimental data "support the hypothesis that there has been directional selection for earlier migration timing, resulting in a substantial decrease in the late-migrating phenotype (from more than 30% to less than 10% of the total abundance)." They also report "from 1983 to 2011, there was a significant decrease-over threefold-in the frequency of

4 http://www.co2science.org/articles/V14/N49/B2.php.
5 http://www.co2science.org/articles/V16/N11/B3.php.

a genetic marker for late-migration timing, but there were minimal changes in allele frequencies at other natural loci."

Commenting on their findings, Kovach *et al*. say "these results demonstrate that there has been rapid microevolution for earlier migration timing in this population," which has allowed both the odd- and even-year groups of salmon "to remain resilient to environmental change," as has also been demonstrated by Kinnison and Hairston (2007). And they note in closing "population abundance in 2011 was the second highest on record," further indicating that the salmon of Auke Creek are "persisting through rapid temperature warming."

Commenting on their findings, Kovach et al. say "these results demonstrate that there has been rapid microevolution for earlier migration timing in this population," which has allowed both the odd- and even-year groups of salmon "to remain resilient to environmental change.

Aurelio *et al*. (2013)[6] examined "the effect of environmental warming on the metabolic and behavioral ecology of a temperate seahorse, *Hippocampus guttulatus*." The examination consisted of comparing routine metabolic rates, thermal sensitivity, ventilation rates, food intake and behavioral patterns at the average spring temperature (18°C), the average summer temperature (26°C), the temperature that seahorses often experience during summer heat wave events (28°C), and the temperature of a near-future warming (+2°C) scenario (= 30°C) in Portugal's Sado estuary.

The ten scientists state "both newborn juveniles and adults showed significant increases in metabolic rates with rising temperatures," with newborn juveniles being "more impacted by future warming via metabolic depression." In addition, "in adult stages, ventilation rates also increased significantly with environmental warming, but food intake remained unchanged." Lastly, they report "the frequency of swimming, foraging, swinging, and inactivity did not significantly change between the different thermal scenarios." And, in light of these several findings, Aurelio *et al*. conclude "adult seahorses show great resilience to heat stress and are not expected to go through any physiological impairment and behavioral change with the projected near-future warming," but they note juveniles in their early life stages "display greater thermal sensitivity and may face greater metabolic challenges," the outcome of which remains unknown.

In a study on adaptation, Bilyk and DeVries (2011)[7] write "most animals do not have a static heat tolerance; rather it changes in response to their recent thermal history through acclimation." However, as they continue, "given the long residence of Antarctic fishes in constant freezing seawater, this plasticity had long been thought either lost or marginal (Brett, 1970)." And they thus say "given the future predicted increases in water temperatures in the

6 http://www.co2science.org/articles/V17/N2/B2.php.
7 http://www.co2science.org/articles/V14/N20/B3.php.

southern Ocean from global climate change, understanding the heat tolerance of Antarctic fishes and its plasticity is critical for understanding the threat to this cold adapted fauna."

In conducting their analysis, Bilyk and DeVries employed the critical thermal maximum (CTMax) methodology-the temperature at which an animal loses the ability to escape from constant rapid warming (Paladino *et al*. 1980)-"to survey heat tolerance in a geographically diverse group of eleven species of Antarctic fishes acclimatized to the cold water temperatures of their natural habitats." They also used this methodology on eight of the species "following warm acclimation to 4°C, which when compared to their environmental CTMaxs provided a measure of the plasticity of their heat tolerance," as they say these fish "had been caught or held at temperatures below -0.9°C."

Results of the analysis revealed "when acclimatized to their natural freezing water temperatures, environmental CTMaxs ranged from 11.95 to 16.17°C," and that when the eight further-studied species were warm-acclimated to 4°C, they found "all showed a significant increase over their environmental CTMaxs, with several showing plasticity comparable in magnitude to some far more eurythermal fishes." Thus, Bilyk and DeVries say "despite their low CTMaxs, all the Antarctic species maintained the capacity to increase their heat tolerance through warm acclimation," and they state when this capacity was quantified, it showed "a surprising level of thermal plasticity at low temperatures," which they say was further surprising "given the presumed loss of selection for thermal flexibility that has long been assumed in this fauna."

In a similar study, Eme *et al*. (2011)[8] write "temperate fishes have been considered especially vulnerable to changing climate conditions," and "increasing water temperatures may also threaten shallow-water marine fishes inhabiting nursery environments, like tropical mangroves and seagrass beds." In an experiment designed to evaluate these hypotheses the authors "used critical thermal methodology to quantify critical thermal maxima (CTmaxima) of juvenile squaretail mullet (*Liza vaigiensis*) and juvenile crescent terapon (*Terapon jarbua*) captured from shallow seagrass nursery areas around Hoga Island, southeast Sulawesi, Indonesia."

The three US researchers report groups of mullet acclimated to a constant temperature of 37°C, as well as temperature *cycles* of 35-39°C or 37-41°C, all displayed statistically similar mean CTmaxima of 44.7, 44.4 and 44.8°C, respectively. And they likewise found terapon acclimated to a constant temperature of 37°C or a temperature cycle of 37 to 40°C both displayed mean CTmaxima of 43.8°C. Given such findings, Eme *et al*. conclude "terapon and mullet demonstrate exceptional tolerance to high temperatures," and they say "it seems likely that shallow-water sea surface temperatures would have to be much higher to adversely affect these and other shallow water marine fishes (Eme and Bennett, 2009)," noting that these "exceptionally high CTmaxima afford mullet and terapon a significant measure of protection against changing habitat conditions." In fact, they write "despite diverse independent origins across taxa, fishes may share a common suite of physiological adaptations allowing them to survive periodic exposure to high environmental temperature (Hochachka and Somero, 2002; Somero, 2010)," and "exceptional thermal tolerance may be common throughout the biodiverse shallow waters

[8] http://www.co2science.org/articles/V14/N22/B1.php.

of the Indo-Pacific." Thus, in the final analysis, they conclude "tropical marine fishes inhabiting fringing nursery environments may have the upper thermal tolerance necessary to endure substantial increases in sea temperatures.

In a controlled laboratory experiment Donelson *et al*. (2012)[9] reared the offspring from eight wild-caught damselfish (*Ancanthochromis polyacanthus*) for two generations, "in present day (+0.0°C) and predicted future increased water temperatures (+1.5°C and +3.0°C) to test their capacity for metabolic acclimation to ocean warming." After a period of three months, the authors assessed the responses in resting metabolic rate (RMR) relative to maximum metabolic rate (MMR) for each individual. This 'metabolic performance' measure was used to characterize changes in the ability of each fish to perform aerobic activities (which would include such functions as behavior, growth and reproduction) at its summer average water temperature (+0.0°C) and above (+1.5°C and +3.0°C).

The experiment revealed second generation offspring had superior metabolic performance at all temperatures when their parents had been reared to maturity at a temperature of +1.5°C or +3.0°C. In addition, one pair of damselfish (i.e. one particular genetic lineage) contributed many more second generation offspring that did well at +3.0°C than did the other wild parents: 75% of all fish that reproduced at +3.0°C were the offspring of wild pair #41. In contrast, wild pair #41 contributed 57% of offspring reproducing at +1.5°C and only 44% of those reproducing at +0.0°C. Thus, in addition to acclimation occurring within two generations, there was also rapid selection of genotypes (and associated phenotypes) tolerant of higher temperatures. Such findings led Donelson *et al*. to conclude "this study provides evidence that, contrary to some expectations, a tropical marine species has the capacity for acclimation and adaptation to temperature increases over timescales much shorter than the rate of anthropogenic climate change" and "the discovery that advantageous offspring phenotypes are produced within two generations could indicate that some tropical marine species are more capable of coping with global warming than has been suggested."

Working with another species of damsel fish, Grenchik *et al*. (2013)[10] introduce their work by noting "tropical ectotherms are predicted to be especially sensitive to global warming because they may possess a narrow thermal tolerance range as a result of having evolved in a relatively stable thermal environment." And they say having a narrow thermal tolerance range would mean "tropical species tend to live close to their thermal optimum," so "even relatively small increases in temperature could lead to declines in individual performance," because "as water temperature increases, so does the cost of maintaining basic cell function (resting metabolic rate, RMR; Bret, 1971)."

In a test on this line of reasoning, Grenchik *et al*. reared newly-settled juveniles of the tropical damselfish *Pomacentrus moluccensis* for a period of four months in four different temperature treatments, which consisted of the current-day summer average (28.5°C) and up to 3°C above the average (29.5, 30.5 and 31.5°C). Based on their analysis, the three Australian researchers discovered that the RMRs of fish reared at 29.5 and 31.5°C were "significantly higher than the

9 http://www.co2science.org/articles/V15/N28/B3.php.
10 http://www.co2science.org/articles/V16/N33/C3.php.

control group reared at 28.5°C," and they indicate "fish that developed in 30.5 and 31.5°C exhibited an enhanced ability to deal with acute temperature increases." To cite the words of Grenchik *et al.*, "this study shows that there is capacity for thermal acclimation during development, with individuals reared from an early age at some temperatures able to modify their physiology to maintain RMRs at near present-day levels," with the result that this developmental thermal acclimation "may assist coral reef fish to cope with increases in water temperature without a substantial loss to performance."

Simpson *et al.* (2011)[11] write "marine ecosystems in the northeast Atlantic have warmed particularly rapidly, with mean sea temperatures in the North Sea and Celtic-Biscay Shelf regions increasing between 1982 and 2006 by 1.31°C and 0.72°C, respectively," which is four times faster than the global average. And in light of these facts, they considered these regions and timeframe to be ideal for determining how real-world fish respond to real-world warming. For their analysis, therefore, the authors "assessed the full impacts of warming on the commercially important European continental shelf fish assemblage using a data-driven Eulerian (grid-based) approach that accommodates spatial heterogeneity in ecological and environmental conditions." This was accomplished by analyzing "local associations of species abundance and community diversity with climatic variables, assessing trends in 172 cells from records of >100 million individuals sampled over 1.2 million km^2 from 1980-2008," rather than relying on macro-ecological analyses of the effects of climate change on marine fish assemblages (as is done with the climate envelope approach) that do not account for "constraints on distributional shifts due to population dependence on essential habitat, such as favored substrates, appropriate predator and prey fields, and close proximity to nursery grounds, all of which are often unknown and difficult to quantify."

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In describing their findings the seven scientists say they discovered "responses to warming in 72% of common species, with three times more species increasing in abundance than declining," and they say they also found these trends "reflected in international commercial landings," where landings of nine species identified as declining in warm conditions fell by a half during the period of their study, whereas landings of 27 species identified as increasing in warm conditions rose by 2.5 times. In addition, they write this "profound reorganization of the relative abundance of species in local communities occurred despite decadal stability in the

[11] http://www.co2science.org/articles/V15/N3/B2.php.

presence-absence of species," such as would have been suggested by the climate envelope approach on a larger spatial scale. Given such, Simpson *et al*. conclude their "finding of stability in presence-absence of species over decadal periods, but significant temperature-driven responses in local species abundance and assemblage composition, suggests that climate envelope models based on species presence-absence alone will not predict the most ecologically and economically significant effects of climate change."

Introducing their study authors Lloyd *et al*. (2012)[12] write "at a broad geographical scale, species richness and diversity decrease as latitude increases both north and south of the equator," and in marine systems they say this distribution pattern "has been linked most consistently to variation in sea temperature," primarily via studies conducted in north-temperate seas, such as those of Fisher *et al*. (2008) and Hiddink and Hofstede (2008).

Noting there is a paucity of such studies from the Southern Hemisphere, Lloyd *et al*. analyzed measurements of sea surface temperature and spear-fishing records pertaining to 84 species of marine fish personally harvested by one of their team: Gyula Plaganyi, a highly skilled and experienced spear-fisher, diving from a small boat anchored at off-shore reef sites located between latitudes 28.0 and 31.6°S on the east coast of South Africa. This was done for each day of diving over the years 1989-2007, over which time interval there was a 0.47°C increase in mean sea surface temperature, which rose from an average of 23.36°C for the period 1989-1996 to an average of 23.83°C for the period 2002-2007.

Large-scale climate change causing a widening of the tropical belt and subsequent ocean warming is having a profound impact on marine species abundance patterns and community composition at a local scale in the sub-tropics. And these changes would appear to be of a positive nature.

With respect to what their data showed, the five Australian researchers report over the specified time interval, "the proportion of the catch made up by temperate species, in terms of both the number and mass of fish, consistently decreased, whereas the proportion of the catch made up by tropical species consistently increased between the two time periods," while "the contribution of broadly distributed species to the overall catch remained approximately the same." In addition, they found "average species richness and diversity increased 33 and 15%, respectively, between the two time periods." Such findings, in the words of the authors, "are broadly consistent with a predicted poleward shift in species ranges and a predicted increase in species richness and diversity with increasing sea temperature," confirming "large-scale climate change causing a widening of the tropical belt and subsequent ocean warming is having a profound impact on marine species abundance patterns and community composition at a local scale in the sub-tropics." And these changes would appear to be of a positive nature.

[12] http://www.co2science.org/articles/V15/N20/B3.php.

Capelin (*Mallotus villosus*) are small short-lived forage fish that are the primary prey of many top predators in northern marine ecosystems. They typically spawn in one of two specific habitats with divergent temperature regimes: beach (warm, variable) and deep water (demersal: cool, stable). And in recent years there has been some concern about how capelin may or may not respond to projected global warming and what the consequences of those actions might be.

In both 2009 and 2010, Davoren (2012)[13] set out to investigate "the influence of temperature on spawning habitat selection in coastal Newfoundland by quantifying habitat-specific temperature, population-level habitat use, and individual-level movements of male capelin via acoustic telemetry." In doing so, the Canadian researcher reports "capelin spawned only at beaches in 2009, when temperatures were significantly colder and frequently fell below suitable ranges at demersal sites, whereas demersal sites were predominantly used under opposing conditions in 2010." And she remarks "males detected in both habitats primarily dispersed from the initial habitat when temperatures routinely fell outside of suitable ranges," noting "this movement often involved traveling long distances (11.0-32.7 km) against currents, suggesting energetic costs."

In discussing the implications of her work, Davoren states "overall, temperature appeared to be an important environmental cue for habitat selection by capelin," and she concludes "the flexible use of spawning habitats under divergent temperature conditions suggests that capelin have a high capacity to respond to and possibly tolerate predicted ocean-climate change."

Introducing their work, Zambonino-Infante *et al*. (2013)[14] write that rising temperatures typically cause "a monotonic decrease in dissolved oxygen concentration in numerous coastal and estuarine ecosystems around the world, resulting in the increased frequency, intensity and length of hypoxia episodes in shallow areas," with a primary consequence of these phenomena being the progressive widening of the gap between the availability of dissolved oxygen in the coastal water and the metabolic demand of various marine animals, which could well spell the difference between their living or dying. Working with the common sole (*Solea solea*), which inhabits shallow marine areas highly exposed to environmental changes, Zambonino-Infante *et al*. "tested whether temperature and trophic conditions experienced during the larval stage had delayed effects on life-history traits and resistance to hypoxia at the juvenile state," thereby examining "the combined effect of global warming and hypoxia in coastal waters, which are potential stressors to many estuarine and coastal marine fishes."

The eight French researchers report the results of their analysis showed "warmer larval temperature had a delayed positive effect on body mass and resistance to hypoxia at the juvenile stage," which finding "suggests a lower oxygen demand of individuals that had experienced elevated temperatures during larval stages." Zambonino-Infante *et al*. thus conclude "this study clearly demonstrates that environmental conditions experienced during early developmental stages are important in controlling environmental adaptation performance at later life stages." More specifically, they state "sole that had experienced elevated

13 http://www.co2science.org/articles/V16/N23/B1.php.
14 http://www.co2science.org/articles/V16/N44/B3.php.

temperatures during their early-life exhibited higher body masses and tolerance to hypoxia, probably through long-term programming of metabolic pathways," noting "such a cohort effect on growth performance and hypoxia tolerance could have major implications for population dynamics." And, therefore, they state the larger implications of the results of their study are "developmental plasticity in animals may allow adaptation to changing environmental conditions to have delayed effects," and "this may attenuate some of the more severe predictions about organisms' responses to global warming and eutrophication."

One year later, Breckels and Neff (2014) report that "genetic adaptations to temperature can occur via natural selection acting on either phenological mechanisms or thermal physiology," citing Angilletta (2009). But they say that "relatively little is known about rapid evolutionary adaptations of thermal physiology (Leal and Gunderson, 2012), especially in vertebrates," although they remark that "Hendry et al. (1998, 2000) provide one of the few empirical examples of a vertebrate, the newly diverged Lake Washington sockeye salmon (*Oncorhynchus nerka*), showing rapid adaptation in thermal tolerance and body shape after only 9-14 generations," which clearly indicates that "vertebrate species can adapt rapidly via evolutionary responses to increased temperature."

In further exploring this intriguing subject, Breckels and Neff studied the phenotypic plasticity and evolutionary responses of sperm traits in guppies (*Poecilia reticulata*) that they maintained for either 6, 18 or 24 months at temperatures of either 25 or 28°C in a 2 x 2 common garden design. The two Canadian researchers report finding that "the plastic response to increased temperature was a decreased sperm length, velocity and path linearity," the last two of which characteristics "showed no sign of evolution even after 24 months." However, in the case of the first of the three characteristics they studied, they found there *was* an evolutionary response, and that it was an *increase in sperm length* that *completely compensated* for the plastic decrease in sperm length after just six months (at most four generations) in 28°C water.

As a result of the above findings, Breckels and Neff concluded that "guppies can respond to climate warming via rapid evolution, at least for some reproductive traits," which reasoning poses the *possibility* that longer time periods may have revealed evolutionary responses to the other two reproductive traits they investigated," as well as the *possibility* that still other traits might likewise exhibit evolutionary responses in both guppies as well as other forms of life, which further suggests that similar types of experiments should be conducted with other life forms and over still longer time periods.

Introducing a different kind of study, Cole *et al*. (2014) write that the types of fish that are most harmed by declining coral cover "are coral-dependent species, such as the obligate coral-feeding butterflyfishes," citing Wilson *et al*. (2006, 2013) and Pratchett *et al*. (2008a), while further noting, in this regard, that several studies have documented "disproportionate declines in the abundance of coral-feeding fishes following severe coral bleaching and coral loss," citing Kokita and Nakazono (2001), Sano (2004), Wilson *et al*. (2006) and Pratchett *et al*. (2006). However, they state that "the effects of short-term or minor bleaching events that do not cause extensive coral mortality are much less clear."

Hoping to bring some clarity to the subject, Cole *et al*. explored "whether there was a difference in the growth and condition of juvenile butterflyfishes inhabiting bleached versus healthy corals," while also examining "whether habitat condition (healthy, bleached and recently dead coral colonies) influenced the patterns of habitat use by juvenile butterflyfishes," which in their case were the species *Chaetodon aureofasciatu*s and *Chaetodon lunulatus*, both of which settle exclusively to distinct colonies of branching corals (Pratchett *et al*., 2008b), and which in their case had recruited in very high abundance to reef habitats on the western side of Lizard Island, northern Great Barrier Reef, Australia, at the time of their study.

The four Australian researchers report finding that "coral condition (bleached vs. unbleached) had no significant effects on changes in [butterflyfish] total length or weight over a 23-day period." Likewise, in a *habitat choice* experiment, they found that "juvenile butterflyfishes did not discriminate between healthy and bleached corals," although they "actively avoided using recently dead colonies." Cole *et al*. concluded that "reef fish communities do appear to exhibit a higher tolerance for bleached coral than initially suspected," highlighting the fact that "juvenile coral-feeding fishes are relatively robust to short term effects of bleaching events."

Finally, Introducing their latest work on the subject, Morris *et al*. (2014) write that "phenotypic plasticity is predicted to facilitate individual survival and/or evolve in response to novel environments," and they say that "plasticity that facilitates survival should both permit colonization and act as a buffer against further evolution, with contemporary and derived forms predicted to be similarly plastic for a suite of traits." In addition, as they continue, "given the importance of plasticity in maintaining internal homeostasis, derived populations that encounter greater environmental heterogeneity should evolve greater plasticity."

In exploring these concepts, Morris *et al*. set out to test "the evolutionary significance of phenotypic plasticity in coastal British Columbian postglacial populations of three spine stickleback (*Gasterosteus aculeatus*) that evolved under greater seasonal extremes in temperature after invading freshwater lakes from the sea." This they did for two ancestral (contemporary marine) and two derived (contemporary freshwater) populations of stickleback that they raised near their thermal tolerance extremes, 7 and 22°C, where gene expression plasticity was estimated for more than 14,000 genes.

In describing their findings the six scientists report that "over five thousand genes were similarly plastic in marine and freshwater stickleback, but freshwater populations exhibited significantly more genes with plastic expression than marine populations." In addition, they found that "several of the loci shown to exhibit gene expression plasticity have been previously implicated in the adaptive evolution of freshwater populations, including a gene involved in mitochondrial regulation." Given such findings, Morris et al. write in the concluding sentence of their paper's abstract, that "collectively, these data provide molecular evidence that highlights the importance of plasticity in colonization and adaptation to new environments." And in the conclusion section of the body of their paper, they say that "these results are consistent with the hypothesis that gene expression plasticity can evolve to meet the challenges of a novel environment." Such findings represent encouraging news for those concerned about animal range expansions or shifts caused by climate change.

In light of all of the findings presented above, it would appear that temperature is much less of a problem for fish (if any at all) than estimated by the IPCC.

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