Supplementary Materials: Recent Advances in Understanding the Effects of Climate Change on Coral Reefs

Andrew S. Hoey, Emily Howells, Jacob L. Johansen, Jean-Paul A. Hobbs, Vanessa Messmer, Dominique M. McCowan, Shaun K. Wilson and Morgan S. Pratchett

Table S1. Recently documented (last 5 years) effects of climate change on reef corals (**a**) declining coral cover; (**b**) reduced diversity and shifts in coral community composition; (**c**) declining or low rates of coral calcification; (**d**) favourable conditions for higher latitude corals; (**e**) recent adaptation and/or acclimatisation (<20 years); and (**f**) longer term adaptation and/or acclimatisation (unknown timescale).

Response	Key Observations	Hypothesised Cause
Declining coral cover	51% loss of coral cover over 27 years (1985 to 2012) on the Great Barrier Reef	10% of coral loss attributed to bleaching [1]
	76% loss of coral cover over 26 years (1974 to 2000) from a reef in the Caribbean	Thermal bleaching and disease [2]
	ca 80% loss of coral cover over 25 years (1977–2002) across 263 sites in the Caribbean	Hurricanes, bleaching and disease [3]
Low diversity and shifts in community composition	41%–48% lower species richness of coral communities in the Persian/Arabian Gulf compared with nearby regions	Extreme summer temperatures, in combination with other environmental variables [4]
	Absence or very low abundance of some coral species from a reef 13 years after major bleaching event in Japan	Failure of some species to survive and recover from bleaching including branching *Porites* and pocilloporids [5]
	Reduced coral cover and changed community composition on a reef 11 years after bleaching and COTS disturbance on the Great Barrier Reef	Loss of *Acropora* spp. with ongoing stressors preventing recovery and promoting a shift towards encrusting *Porites* spp. and soft corals [6]
	Species-specific mortality of corals during 3 months exposure of mesocosm communities to future scenarios of elevated temperature and lowered pH (up to +4 °C,+572 μatm pCO_2)	Predicted loss of sensitive acroporids and pocilloporid corals from reefs in the future [7]
	39% lower species richness of coral communities at carbon dioxide seeps (Ω_{arag} ~2.5) in Papua New Guinea compared with non-seep sites	Low saturation state of aragonite [8]
	67% lower species richness of coral communities at sites of discharge of low pH groundwater (Ω_{ar} <2.5) in the Mexican Caribbean compared with control sites (Ω_{ar} > 2.5)	Low saturation state of aragonite [9]
Declining or low rates of coral calcification	20%–30% decline in calcification of massive corals from the Great Barrier Reef (*Porites* massive, 1989–2002) and the Mesoamerican Barrier Reef (*Porites astreoides* and *Orbicella* spp., 1977–2009)	Rising sea temperatures [10]
	20% decline in calcification of *Porites* massive colonies in SE Asia from 1980–2010	Rising sea temperatures in 4/6 locations [11]
	11% decline in the calcification rate of *Porites* massive corals on the Great Barrier Reef from 1990-2005	Rising seas temperature and/or lowered saturation state of aragonite [12]
	58% lower calcification rates in *Porites astreoides* colonies living at a site of discharge of low pH groundwater (Ω_{arag} < 1) in the Mexican Caribbean compared with control site (Ω_{arag} > 3.5)	Low saturation state of aragonite [13]

Table S1. *Cont.*

Response	Key Observations	Hypothesised Cause
Favourable conditions for temperate corals	Increased calcification rates of *Porites* massive corals on high latitude reefs of Western Australia	Increased duration of favourable temperatures for growth [14]
	Increased distribution at cool-edges of species ranges in Japan (unaccompanied by contractions at warm ranges) for *Acropora hyacinthus*, *Acropora muricata*, *Acropora solitaryensis*, and *Pavona decusata*	Increase in winter temperatures above cold tolerance thresholds [15]
Recent adaptation and/or acclimatisatio n (<20 years)	Increase in the resistance of *Acropora* and *Montipora* to bleaching across multiple thermal anomalies from 1991 to 2007 in Moorea	Adaptation through selective mortality of sensitive genotypes (although acclimatization could not be excluded) [16]
	Increased resistance of *Acropora* and *Pocillopora* corals to bleaching in 2010 compared with 1998 in SE Asia	Recent acclimatization or adaptation to anomalous temperatures [17]
	Higher than expected bleaching thresholds of multiple coral genera including *Acropora,* branching *Porites, Montipora* and *Stylophora* during a thermal anomaly in 2005 in the Maldives	Recent acclimatization or adaptation to anomalous temperatures [18]
	Experimental increase in thermal tolerance after prior exposure to heat in *Acropora millepora* from the Great Barrier Reef	Acclimatisation measured by small transcriptional changes in the host [19,20]
	Increased thermal tolerance of *Platygyra verweyi* adjacent to outflow of a nuclear power plant in Taiwan	Acclimatisation via associations with a thermally tolerant symbiont type [21]
	Resistance to experimental repeat bleaching in *Porites divaricata* from the Caribbean (but not 2 other tested species)	Change in dominant symbiont type and high energy reserves in the host [22]
	Increased thermal tolerance of *Acropora* spp. and *Pocillopora* spp. corals in tidal pools exposed to short durations of high temperature	Acclimatization via associations with thermally tolerant symbiont type [23]
	Acquisition of thermal tolerance in *Acropora hyacitnthus* transplanted to habitat experiencing more variable and higher maximum temperatures in American Samoa	Acclimatisation over ~1-2 years measured by transcriptional changes in the host [24]
Longer term adaptation and/or acclimatisatio n (unknown timescale)	Fixed higher thermal tolerance of *Acropora hyacinthus* from a warmer environment following 1–2 years of reciprocal transplantation	Long term acclimatisation or local adaptation of the coral host [24]
	Enhanced thermal tolerance of *Acropora millepora* larvae with parents from warm vs. cool environments on the Great Barrier Reef	Local adaptation of coral host populations; beneficial alleles passed on to offspring [25]
	Experimentally higher thermal tolerance of inshore vs. offshore *Porites astreoides* corals in the Florida Keys	Long term acclimatisation or local adaptation of the coral host [26,27]
	Experimentally higher thermal tolerance of adult and larval *Platygyra daedalea* corals from the hot Persian Gulf vs. the milder Oman Sea	Local adaptation of both coral host and symbiont populations [28]
	Experimentally higher thermal tolerance of *Acropora millepora* hosting populations of the same symbiont type from different regions	Local adaptation of symbiont populations [29]; see also [30]
	No temporal change (1982–2002) of the calcification rate of *Siderastrea siderea* from thermally variable back-reef habits compared with the more thermally uniform back-reef and nearshore habitats in Belize	Acclimatisation or adaptation to thermally fluctuating temperatures improved resilience to long-term rises in sea temperature [31]
	Similar calcification rates in *Porties* massive corals from carbon dioxide seep (Ω_{arag} ~2.5) vs. non-seep communities in Papua New Guinea	Calcification of *Porites* massive colonies insensitive to lowered pH [8]
	Similar calcification in *Porites* massive corals from a low (Ω_{arag} 2.3) vs. ambient pH site in Palau	Calcification of *Porites* massive colonies insensitive to lowered pH [32]

References

1. De'ath, G.; Fabricius, K.E.; Puotinen, S.H. The 27–year decline of coral cover on the Great Barrier Reef and its causes. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 17995–17999.
2. Alevizon, W.S.; Porter, J.W. Coral loss and fish guild stability on a Caribbean coral reef: 1974–2000. *Environ. Biol. Fish.* **2015**, *98*, 1035–1045.
3. Gardiner, T.A.; Cote, I.M.; Gill, J.A.; Grant, A.; Watkinson, A.R. Long-term region-wide declines in Caribbean corals. *Science* **2003**, *301*, 958–960.
4. Bauman, A.G.; Feary, D.A.; Heron, S.F.; Pratchett, M.S.; Burt, J.A. Multiple environmental factors influence the spatial distribution and structure of reef communities in the northeastern Arabian Peninsula. *Mar. Poll. Bull.* **2013**, *72*, 302–312.
5. Van Woesik, R.; Sakai, K.; Ganase, A.; Loya, Y. Revisiting the winners and the losers a decade after coral bleaching. *Mar. Ecol. Prog. Ser.* **2011**, *434*, 67–76.
6. Johns, K.; Osborne, K.; Logan, M. Contrasting rates of coral recovery and reassembly in coral communities on the Great Barrier Reef. *Coral Reefs* **2014**, *33*, 553–563.
7. Dove, S.G.; Kline, D.I.; Pantos, O.; Angly, F.E.; Tyson, G.W.; Hoegh-Guldberg, O. Future reef decalcification under a business-as-usual CO2 emission scenario. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 15342–15347.
8. Fabricius, K.E.; Langdon, C.; Uthicke, S.; Humphrey, C.; Noonan, S.; De'ath, G.; Okazaki, R.; Muehllehner, N.; Glas, M.S.; Lough, J.M. Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. *Nat. Clim. Chang.* **2011**, *1*, 165–169.
9. Crook, E.D.; Potts, D.; Rebolledo-Vieyra, M.; Hernandez, L.; Paytan, A. Calcifying coral abundance near low-pH springs: Implications for future ocean acidification. *Coral Reefs* **2012**, *31*, 239–245.
10. Carricart-Ganivet, J.P.; Cabanillas-Teran, N.; Cruz-Ortega, I.; Blanchon, P. Sensitivity of calcification to thermal stress varies among genera of massive reef-building corals. *PLoS ONE* **2012**, *7*, e32859.
11. Tanzil, J.T.; Brown, B.E.; Dunne, R.P.; Lee, J.N.; Kaandorp, J.A.; Todd, P.A. Regional decline in growth rates of massive Porites corals in Southeast Asia. *Glob. Chang. Biol.* **2013**, *19*, 3011–3023.
12. De'ath, G.; Lough, J.M.; Fabricius, K.E. Declining coral calcification on the Great Barrier Reef. *Science* **2009**, *323*, 116–119.
13. Crook, E.D.; Cohen, A.L.; Rebolledo-Vieyra, M.; Hernandez, L.; Paytan, A. Reduced calcification and lack of acclimatization by coral colonies growing in areas of persistent natural acidification. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 11044–11049.
14. Cooper, T.F.; O'Leary, R.A.; Lough, J.M. Growth of Western Australian corals in the Anthropocene. *Science* **2012**, *335*, 593–596.
15. Yamano, H.; Sugihara, K.; Nomura, K. Rapid poleward range expansion of tropical reef corals in response to rising sea surface temperatures. *Geophys. Res. Lett.* **2011**, 38.
16. Pratchett, M.S.; McCowan, D.; Maynard, J.A.; Heron, S.F. Changes in bleaching susceptibility among corals subject to ocean warming and recurrent bleaching in Moorea, French Polynesia. *PLoS ONE* **2013**, *8*, e70443.
17. Guest, J.R.; Baird, A.H.; Maynard, J.A.; Muttaqin, E.; Edwards, A.J.; Campbell, S.J.; Yewdall, K.; Affendi, Y.A.; Chou, L.M. Contrasting patterns of coral bleaching susceptibility in 2010 suggest an adaptive response to thermal stress. *PLoS ONE* **2012**, *7*, e33353.
18. McClanahan, T.; Muthiga, N. Community change and evidence for variable warm-water temperature adaptation of corals in Northern Male Atoll, Maldives. *Mar. Poll. Bull.* **2014**, *80*, 107–113.
19. Bellantuono, A.J.; Hoegh-Guldberg, O.; Rodriguez-Lanetty, M. Resistance to thermal stress in corals without changes in symbiont composition. *Proc. R. Soc. B* **2011**, rspb20111780.
20. Bellantuono, A.J.; Granados-Cifuentes, C.; Miller, D.J.; Hoegh-Guldberg, O.; Rodriguez-Lanetty, M. Coral thermal tolerance: tuning gene expression to resist thermal stress. *PLoS ONE* **2012**, *7*, e50685.
21. Keshavmurthy, S.; Hsu, C.M.; Kuo, C.Y.; Meng, P.J.; Wang, J.T.; Chen, C.A. Symbiont communities and host genetic structure of the brain coral *Platygyra verweyi*, at the outlet of a nuclear power plant and adjacent areas. *Mol. Ecol.* **2012**, *21*, 4393–4407.
22. Grottoli, A.G.; Warner, M.E.; Levas, S.J.; Aschaffenberg, M.D.; Schoepf, V.; McGinley, M.; Baumann, J.; Matsui, Y. The cumulative impact of annual coral bleaching can turn some coral species winners into losers. *Glob. Chang. Biol.* **2014**, 10.1111/gcb.12658

23. Oliver, T.; Palumbi, S.R. Do fluctuating temperature environments elevate coral thermal tolerance? *Coral Reefs* **2011**, *30*, 429–440.
24. Palumbi, S.R.; Barshis, D.J.; Traylor-Knowles, N.; Bay, R.A. Mechanisms of reef coral resistance to future climate change. *Science* **2014**, *344*, 895–898.
25. Dixon, G.B.; Davies, S.W.; Aglyamova, G.A.; Meyer, E.; Bay, L.K.; Matz, M.V. Genomic determinants of coral heat tolerance across latitudes. *Science* **2015**, *348*, 1460–1462.
26. Kenkel, C.; Meyer, E.; Matz, M. Gene expression under chronic heat stress in populations of the mustard hill coral (*Porites astreoides*) from different thermal environments. *Mol. Ecol.* **2013**, *22*, 4322–4334.
27. Kenkel, C.; Goodbody-Gringley, G.; Caillaud, D.; Davies, S.W.; Bartels, E.; Matz, M.V. Evidence for a host role in thermotolerance divergence between populations of the mustard hill coral (*Porites astreoides*) from different reef environments. *Mol. Ecol.* **2013**, *22*, 4335–4348.
28. Howells, E.J.; Abrego, D.; Meyer, E.; Kirk, N.L.; Burt, J.A. Host adaptation and unexpected symbiont partners enable reef-building corals to tolerate extreme temperatures. *Glob. Chang. Biol.* **2016,** doi:10.1111/gcb.13250
29. Howells, E.J.; Beltran, V.H.; Larsen, N.W.; Bay, L.K.; Willis, B.L.; Van Oppen, M.J.H. Coral thermal tolerance shaped by local adaptation of photosymbionts. *Nat. Clim. Chang.* **2012**, *2*, 116–120.
30. Jones, A.M.; Berkelmans, R.; van Oppen, M.J.H.; Mieog, J.C.; Sinclair, W. A community change in the algal endosymbionts of a scleractinian coral following a natural bleaching event: Field evidence of acclimatization. *Proc. R. Soc. B* **2008**, *275*, 1359-1365
31. Castillo, K.D.; Ries, J.B.; Weiss, J.M.; Lima, F.P. Decline of forereef corals in response to recent warming linked to history of thermal exposure. *Nat. Clim. Chang.* **2012**, *2*, 756–760.
32. Shamberger, K.E.; Cohen, A.L.; Golbuu, Y.; McCorkle, D.C.; Lentz, S.J.; Barkley, H.C. Diverse coral communities in naturally acidified waters of a Western Pacific Reef. *Geophys. Res. Lett.* **2014**, *41*, 499–504.

Table S2. Summary table of the effects of elevated seawater temperature on the activity, development, metabolism, reproduction, and sensory capabilities of coral reefs fishes. "+" indicates positive, "-" indicates negative, and "ns" no significant effect.

Type	Response	Family	Species	Life Stage	Control (°C)	Treatment (°C)	Exposure (days)	Effect	Source
Activity	Swim performance	Pomacentridae	*Chromis atripectoralis*	adult	29	32	21	ns	[1]
		Pomacentridae	*Chromis ternatensis*	adult	29	32	21	ns	[1]
		Pomacentridae	*Dascyllus aruanus*	adult	29	32	21	-	[1]
		Pomacentridae	*Dascyllus reticulatus*	adult	29	32	21	-	[1]
		Pomacentridae	*Neopomacentrus azysron*	adult	29	32	21	ns	[1]
		Pomacentridae	*Neopomacentrus bankieri*	adult	29	32	21	ns	[1]
		Pomacentridae	*Neopomacentris cyanomos*	adult	29	32	21	-	[1]
		Pomacentridae	*Pomacenturs coelestis*	adult	29	32	21	-	[1]
		Pomacentridae	*Pomacentrus lepidogenys*	adult	29	32	21	-	[1]
		Pomacentridae	*Pomacentrus moluccensis*	adult	29	32	21	ns	[1]
	Swim speed	Serranidae	*Plectropomus leopardus*	adult	27	24	42	ns	[2]
						30		-	
						33		-	
	Time resting	Serranidae	*P. leopardus*	adult	27	24	42	ns	[2]
						30		+	
						33		+	
	Routine activity	Pomacentridae	*Amphiprion melanopus*	larva	28.5	30	21	ns	[3]
						31.5		ns	
	Food intake	Pomacentridae	*A. melanopus*	larva	28.5	30	21	+	[3]
						31.5		ns	
		Serranidae	*P. leopardus*	adult	27	24	42	ns	[4]
						30		+	
						33	7	+	
Development	Body condition	Pomacentridae	*Acanthochromis polyacanthus*	adult	22.5–28.5	24–30		ns	[5]
						25.5–31.5		ns	
	Fat	Pomacentridae	*A. polyacanthus*	adult	28.5	30	~ 180	ns	[6]
						31.5		ns	
	Body length	Pomacentridae	*A melanopus*	juvenile	28.5	30	32	ns	[7]
						31.5		-	
		Pomacentridae	*S. partitus*	larva	natural field temperatures			+	[8]

Table S2. *Cont.*

Type	Response	Family	Species	Life Stage	Control (°C)	Treatment (°C)	Exposure (days)	Effect	Source
		Pomacentridae	*A. percula*	larva	29.2	30.7	8–19	ns	[9]
						32.2		ns	
	Mass	Pomacentridae	*A melanopus*	juvenile	28.5	30	32	ns	[7]
						31.5		ns	
	Growth	Pomacentridae	*Pomacentrus amboboinensis*	larva	28.3	31.1	4	ns	[10]
		Pomacentridae	*Pomacentrus nagasakiensis*	larva	28.3	31.1	4	ns	[10]
		Pomacentridae	*A. polyacanthus*	adult	28.5	30	~180	-	[6]
						31.5		-	
		Pomacentridae	*S. partitus*	larva	natural field temperatures			+	[8]
	PLD	Pomacentridae	*Stegastes partitus*	larva	natural field temperatures			-	[8]
		Pomacentridae	*Amphiprion percula*	larva	29.2	30.7	8–19	ns, +	[9]
						32.2		ns, +	
	Survival	Pomacentridae	*A. melanopus*	juvenile	28.5	30	32	+	[7]
						31.5		+	
		Pomacentridae	*P. amboinensis*	larva	28.3	31.1	4	ns	[10]
		Pomacentridae	*P. nagasakiensis*	larva	28.3	31.1	4	ns	[10]
Metabolism	RMR	Apogonidae	*O. doederleini*	adult	28.5–29.5	32	7–22	+	[11]
			O. doederleini	adult	29	31	7	ns	[12]
						32	7	+	
			O. cyanosoma	adult	29	31	7	+	[12]
						32	7	+	
			C quinquelineatus	adult	29	31	12–14	ns	[13]
						33		ns	
						34		ns	
			Zoramia leptacantha	adult	29	31	12–14	ns	[13]
						33		ns	
						34		ns	
		Pomacentridae	*A melanopus*	juvenile	28.5	30	32	+	[7]
						31.5		+	
			P. amboinensis	larva	28.3	31.1	4	ns	[10]
			P. nagasakiensis	larva	28.3	31.1	4	ns	[10]

Table S2. *Cont.*

Type	Response	Family	Species	Life Stage	Control (°C)	Treatment (°C)	Exposure (days)	Effect	Source
			A. polyacanthus	juvenile	22.5–28.5	24–30	365	+	[14]
						25.5–31.5		+	
			A. polyacanthus	adult	29	31	12–14	ns	[13]
						33		ns	
			P. moluccensis	adult	29	31	12–14	ns	[13]
						33		+	
						34		+	
			Dascyllus melanurus	adult	29	31	12–14	ns	[13]
						33		ns	
						34		+	
			C. atripectoralis	adult	29	31	12–14	+	[13]
						33		+	
						34		+	
			P. moluccensis	adult	28.5–29.5	32	7–22	+	[11]
			A. percula	larva	29.2	32.2	8–19	+	[9]
	MMR	Apogonidae	*O. doederleini*	adult	29	31	7	ns	[12]
						32	7	ns	
			O. cyanosoma	adult	29	31	7	ns	[12]
						32	7	ns	
			C quinquelineatus	adult	29	31	12–14	ns	[13]
						33		-	
						34		-	
			Z. leptacantha	adult	29	31	12–14	ns	[13]
						33		ns	
						34		-	
		Pomacentridae	*A. polyacanthus*	adult	29	31	12-14	ns	[13]
						33		ns	
			P. moluccensis	adult	29	31	12–14	ns	[13]
						33		+	
						34		+	
			D. melanurus	adult	29	31	12–14	-	[13]
						33		ns	
						34		ns	

Table S2. *Cont.*

Type	Response	Family	Species	Life Stage	Control (°C)	Treatment (°C)	Exposure (days)	Effect	Source
			C. atripectoralis	adult	29	31	12–14	-	[13]
						33		-	
						34		-	
	Aerobic scope	Apogonidae	*Ostorhinchus cyanosoma*	adult	29	31	7	ns	[12]
						32	7	ns	
			Ostorhinchus doederleini	adult	29	31	7	ns	[12]
						32	7	ns	
		Pomacentridae	*C. atripectoralis*	adult	29	32	21	ns	[1]
			C. ternatensis	adult	29	32	21	-	[1]
			D. aruanus	adult	29	32	21	ns	[1]
			D. reticulatus	adult	29	32	21	-	[1]
			N. azysron	adult	29	32	21	ns	[1]
			N. bankieri	adult	29	32	21	ns	[1]
			N. cyanomos	adult	29	32	21	-	[1]
			P. coelestis	adult	29	32	21	-	[1]
			P lepidogenys	adult	29	32	21	-	[1]
			P. moluccensis	adult	29	32	21	ns	[1]
]Reproduction	Yolk area	Pomacentridae	*A. polyacanthus*	adult	22.5–28.5	24–30		-	[5]
						25.5–31.5		-	
	Egg size	Pomacentridae	*A. polyacanthus*	adult	28.5	30	~180	-	6
						31.5		-	
	Offspring size	Pomacentridae	*A polyacanthus*	adult	22.5–28.5	24–30		-	[5]
						25.5–31.5		-	
Behaviour	Lateralisation	Pomacentridae	*Pomacentrus wardi*	larva	26.7	29.6	7 days	-	[15]

References

1. Johansen, J.L.; Jones, G.P. Increasing ocean temperature reduces the metabolic performance and swimming ability of coral reef damselfishes. *Glob. Chang. Biol.* **2011**, *17*, 2971–2979.
2. Johansen, J.L.; Messmer, V.; Coker, D.J.; Hoey, A.S.; Pratchett, M.S. Increasing ocean temperatures reduce activity patterns of a large commercially important coral reef fish. *Glob. Chang. Biol*. **2014**, *20*, 1067–1074.
3. Nowicki, J.P.; Miller, G.M.; Munday, P.L. Interactive effects of elevated temperature and CO_2 on foraging behavior of juvenile coral reef fish. *J. Exp. Mar. Biol. Ecol.* **2012**, *412*, 46–51.
4. Johansen, J.L.; Pratchett, M.S.; Messmer, V.; Coker, D.J.; Tobin, A.J.; Hoey, A.S. Large predatory coral trout species unlikely to meet increasing energetic demands in a warming ocean. *Sci. Rep.* **2015**, *5*, 13830.
5. Donelson, J.M.; Munday. P.L.; McCormick, M.I. Climate change may affect fish through an interaction of parental and juvenile environments. *Coral Reefs*. **2012**, *31*, 753–762.
6. Donelson, J.M.; Munday, P.L.; McCormick, M.I.; Pankhurst, N.W.; Pankhurst, P.M. Effects of elevated water temperature and food availability on the reproductive performance of a coral reef fish. *Mar. Ecol. Prog. Ser*. **2010**, *401*, 233–245.
7. Miller, G.M.; Watson, S.A.; Donelson, J.M.; McCormick, M.I.; Munday, P.L. Parental environment mediates impacts of increased carbon dioxide on a coral reef fish. *Nat. Clim. Chang.* **2012**, *2*, 858–861.
8. Rankin, T.L., Sponaugle, S. Temperature influences selective mortality during the early life stages of a coral reef fish. *PLoS ONE* **2011**, *6*, e16814.
9. McLeod, I.M.; Rummer, J.L.; Clark, T.D.; Jones, G.P.; McCormick, M.I.; Wenger, A.S.; Munday, P.L. Climate change and the performance of larval coral reef fishes: the interaction between temperature and food availability. *Conserv. Physiol*. **2013**, *1*, cot024.
10. Ferrari, M.; Munday, P.L.; Rummer, J.L.; McCormick, M.I.; Corkill, K.; Watson, S.A.; Allan, B.J.; Meekan, M.G.; Chivers, D.P. Interactive effects of ocean acidification and rising sea temperatures alter predation rate and predator selectivity in reef fish communities. *Glob. Change Biol.* **2015**, *21*, 1848–55.
11. Nilsson, G.E.; Östlund-Nilsson, S.; Munday, P.L. Effects of elevated temperature on coral reef fishes: loss of hypoxia tolerance and inability to acclimate. *Comp. Biochem. Physiol. A* **2010**, *156*, 389–93.
12. Munday, P.L.; Crawley, N.E.; Nilsson, G.E. Interacting effects of elevated temperature and ocean acidification on the aerobic performance of coral reef fishes. *Mar. Ecol. Prog. Ser.* **2009**, *388*, 235–242.
13. Rummer, J.L.; Couturier, C.S.; Stecyk, J.A.; Gardiner, N.M.; Kinch, J.P.; Nilsson, G.E.; Munday, P.L. Life on the edge: thermal optima for aerobic scope of equatorial reef fishes are close to current day temperatures. *Glob. Chang. Biol.* **2014**, *20*, 1055–1066.
14. Donelson, J.M.; Munday, P.L.; McCormick, M.I.; Nilsson, G.E. Acclimation to predicted ocean warming through developmental plasticity in a tropical reef fish. *Glob. Chang. Biol.* **2011**, 17, 1712–1719.
15. Domenici, P.; Allan, B.; McCormick, M.I.; Munday, P.L. Elevated carbon dioxide affects behavioural lateralization in coral reef fish. *Biol. Lett*. **2012**, rsbl20110591.

Table S3. Summary table of the effects of ocean acidification on the activity, development, metabolism, reproduction, sensory capabilities, and survival of coral reefs fishes. Numbers in parentheses for control and treatment CO_2 are the pH of the seawater. "+" indicates positive, "-" indicates negative, and "ns" no significant effect. '*' denotes study was conducted around natural CO_2 seeps and as such an exposure time is not given.

Field	Response	Family	Species	Life stage	Control CO_2 (ppm)	Treatment CO_2 (ppm)	Exposure (days)	Effect	Source
Activity	Activity	Pomacentridae	*Amphiprion melanopus*	larva	410-433	511–551	21	ns	[1]
						912–1020		ns	
			Pomacentrus amboinensis	larva	441 (8.15)	554 (8.06)	4	ns	[2]
				larva		718 (7.97)	4	ns	
				larva		880 (7.89)	4	-	
		Pseudochromidae	*Pseudochromis fuscus*	adult	444 (8.14)	607 (8.05)	4–7	ns	[3]
						925 (7.87)		+	
	Boldness	Serranidae	*Plectropomus leopardus*	juvenile	490 (8.1)	550 (8.04)	28	ns	[4]
						690 (7.97)		+	
						940 (7.85)		+	
		Pomacentridae	*Pomacentrus wardi*	larva	425 (8.16)	704 (7.98)	4	+	[5]
			Dascyllus aruanus	juvenile	346–413	441–998	*	+	[6]
			Pomacentrus moluccensis	juvenile	346–413	441–998	*	+	[6]
		Apogonidae	*Ostorhinchus cyanosoma*	juvenile	346–413	441–998	*	+	[6]
			Cheilodipterus quinquelineatus	juvenile	346–413	441–998	*	+	[6]
	Learning	Pomacentridae	*P. amboinensis*	larva	441 (8.15)	880 (7.89)	4	-	[7]
	Anti-predator response	Pomacentridae	*P. amboinensis*	larva	390	700	4	-	[8]
						850	4	-	
			P. ambonensis	larva	441 (8.15)	880 (7.89)	4	-	[9]
			Pomacentrus chrysurus	larva	390	700	4	-	[8]
						850	4	-	
			P. moluccensis	larva	390	700	4	-	[8]
						850	4	-	
			Pomacentrus nagasakiensis	larva	390	700	4	-	[8]
						850	4	-	
			A. melanopus	larva	400 (8.15)	1087 (7.81)	11	-	[10]
	Feeding	Pomacentridae	*P. wardi*	larva	425 (8.16)	704 (7.98)	4	ns	[5]
			P. amboinensis	larva	440 (8.15)	987 (7.85)	4	-	[11]
			P. amboinensis	larva	441 (8.15)	880 (7.89)	4	-	[7]
		Hemiscylliidae	*Hemiscyllium ocellatum*	juvenile	390	615	60	ns	[12]

Table S3. *Cont.*

Field	Response	Family	Species	Life stage	Control CO_2 (ppm)	Treatment CO_2 (ppm)	Exposure (days)	Effect	Source
						910		ns	
	Reaction distance	Pomacentridae	*P. ambonensis*	larva	441 (8.15)	880 (7.89)	4	ns	[9]
	Shelter use	Pomacentridae	*P. amboinensis*	larva	441 (8.15)	880 (7.89)	4	ns	[7]
	Swim speed	Pomacentridae	*Amphiprion percula*	larva	396 (8.06)	538 (7.94)	11	ns	[13]
						744 (7.88)		ns	
						1024 (7.84)		ns	
Develop ment	Growth	Serranidae	*P. leopardus*	juvenile	490 (8.1)	550 (8.04)	28	ns	[4]
						690 (7.97)		ns	
						940 (7.85)		ns	
		Pomacentridae	*Acanthochromis polyacanthus*	larva	455 (8.07)	589 (7.95)	21	ns	[14]
						723 (7.88)		ns	
						840 (7.83)		ns	
	Otolith size	Pomacentridae	*A. percula*	Larva	404 (8.15)	1051 (7.8)	17–19	ns	[15]
						1721 (7.6)		+	
	Size at settlement	Pomacentridae	*A. percula*	larva	396 (8.06)	538 (7.94)	11	ns, +	[13]
						744 (7.88)		ns, +	
						1024 (7.84)		ns, +	
	Body size	Pomacentridae	*A melanopus*	juvenile	430 (8.11)	1032 (7.77)	32	-	[16]
			P. amboinensis	larva	436 (8.15)	985 (7.85)	4	ns	[17]
			P. nagasakiensis	larva	436 (8.15)	985 (7.85)	4	ns	
Metaboli sm	SMR	Pomacentridae	*P. amboinensis*	larva	451	860	4	ns	[18]
			P. moluccensis	larva	451	860	4	ns	[18]
			A. melanopus	juvenile	430 (8.11)	1032 (7.77)	32	ns	[16]
			A. polyacanthus	adult	451	946	17	-	[19]
			P. amboinensis	larva	436 (8.15)	985 (7.85)	4	ns	[17]
			P. nagasakiensis	larva	436 (8.15)	985 (7.85)	4	ns	[17]
		Pseudochromidae	*P. fuscus*	adult	451	860	4	ns	[18]
		Hemiscylliidae	*H. ocellatum*	adult	390	600	60	ns	[20]
						880		ns	

Table S3. *Cont.*

Field	Response	Family	Species	Life stage	Control CO_2 (ppm)	Treatment CO_2 (ppm)	Exposure (days)	Effect	Source
	MMR	Pomacentridae	*A. polyacanthus*	adult	451	946	17	+	[19]
			P. amboinensis	larva	451	860	4	+	[18]
			P. amboinensis	larva	451	860	6 mins	+	[18]
			P. moluccensis	larva	451	860	4	ns	[18]
			P. moluccensis	larva	451	860	6 mins	ns	[18]
		Pseudochromidae	*P. Fuscus*	adult	451	860	4	ns	[18]
	Aerobic scope	Apogonidae	*Ostorhinchus doederleini*	adult	(8.15)	(7.8)	7	-	[21]
			O. cyanosoma	adult	(8.15)	(7.8)		-	[21]
		Pomacentridae	*A. polyacanthus*	adult	451	946	17	+	[19]
			P. moluccensis	juvenile	346–413	441–998		ns	[6]
			D. aruanus	juvenile	346–413	441–998	*	ns	[6]
Reproduction	Number of clutches	Pomacentridae	*A. melanopus*	adult	430 (8.11)	584 (8.01)	60–280	ns	[22]
						1032 (7.77)		+	
	Number of eggs	Pomacentridae	*A. melanopus*	adult	430 (8.11)	584 (8.01)	60–280	ns	[22]
						1032 (7.77)		+	
	Yolk sac area	Pomacentridae	*A. melanopus*	adult	430 (8.11)	584 (8.01)	60–280	ns	[22]
						1032 (7.77)		-	
			A. percula	eggs	396 (8.06)	1024 (7.84)	6–8	-	[13]
	Size at hatching	Pomacentridae	*A. percula*	eggs	396 (8.06)	1024 (7.84)	6–8	ns	[13]
	Embryonic duration	Pomacentridae	*A. percula*	eggs	396 (8.06)	1024 (7.84)	6–8	ns	[13]
	Egg survival	Pomacentridae	*A. percula*	eggs	396 (8.06)	1024 (7.84)	6–8	ns	[13]
Sensory	Auditory	Pomacentridae	*A. percula*	larva	390	610	17–20	-	[23]
						720		-	
						870		-	
	Habitat choice	Gobiidae	*Gobiodon histrio*	adult	441 (8.15)	880 (7.89)	4	-	[24]
	Lateralisation	Pomacentridae	*Neopomacentrus azysron*	larva	440 (8.1)	880 (7.9)	4	-	[25]
			N. azysron	larva	440	880	4	-	[26]
			P. wardi	larva	405	930	7	-	[27]
	Olfaction	Pomacentridae	*A. percula*	larva	(8.15)	(7.8)	11	-	[28]

Table S3. *Cont.*

Field	Response	Family	Species	Life stage	Control CO_2 (ppm)	Treatment CO_2 (ppm)	Exposure (days)	Effect	Source
			A. percula	larva	380 (8.15)	1000 (7.8)	11	-	[29]
						1700 (7.6)		-	
			A. percula	larva	390	540	10	ns	[30]
						700		-	
						850		-	
			A. percula	larva	450 (8.1)	945 (7.8)	11	-	[25]
			P. amboinensis	larva	450	678	4–5	-	[31]
						875	4–5	ns	
			P amboinensis	larva	441 (8.15)	880 (7.89)	4	-	[7]
			P. chrysurus	larva	450	678	4–5	ns	[31]
						875	4–5	-	
			P. moluccensis	larva	450	678	4–5	-	[31]
						875	4–5	-	
			P. wardi	larva	425 (8.16)	704 (7.98)	4	-	[5]
			P. leopardus	juvenile	490 (8.1)	550 (8.04)	28	ns	[4]
						690 (7.97)		-	
						940 (7.85)		-	
		Gobiidae	*Paragobiodon xanthosomus*	adult	441 (8.15)	880 (7.89)	4	-	[24]
		Apogonidae	*C. quinquelineatus*	adult	390	550	4	-	[32]
			C. quinquelineatus	adult		700	4	-	
			C. quinquelineatus	adult		950	4	-	
		Pseudochromidae	*P. fuscus*	adult	451 (8.16)	630 (8.03)	4–7	+	[3]
	Retinal function	Pomacentridae	*A. polyacanthus*	adult	466 (8.13)	944 (7.87)	6–7	-	[33]
	Vision	Pomacentridae	*P. amboinensis*	larva	441 (8.15)	880 (7.89)	4	ns	[7]
Survival	Survivorship	Pomacentridae	*A. melanopus*	juvenile	430 (8.11)	1032 (7.77)	32	-	[16]
			P. amboinensis	larva	440 (8.15)	987 (7.85)	4	-	[11]
			P. amboinensis	larva	400	700	4	ns	[34]
				juvenile	400	700	4	ns	[34]
			P. amboinensis	larva	436 (8.15)	985 (7.85)	4	ns	[17]
			P. chrysurus	larva	400	700	4	-	[34]
				juvenile	400	700	4	ns	[34]
			P. chrysurus	larva	390	700	4	-	[8]

Table S3. *Cont.*

Field	Response	Family	Species	Life stage	Control CO_2 (ppm)	Treatment CO_2 (ppm)	Exposure (days)	Effect	Source
				larva		850	4	-	
			P. moluccensis	larva	400	700	4	-	[34]
				juvenile	400	700	4	ns	[34]
			P. nagasakiensis	larva	400	700	4	-	[34]
				juvenile	400	700	4	ns	[34]
			P. nagasakiensis	larva	436 (8.15)	985 (7.85)	4	ns	[17]
			P. wardi	larva	390	540	4	-	[30]
						700		-	
						850		-	
			P. wardi	larva	425 (8.16)	704 (7.98)	4	-	[5]
	Predation success	Pseudochromidae	*P. fuscus*	adult	441 (8.15)	880 (7.89)	4	ns	[9]

References

1. Nowicki, J.P.; Miller, G.M.; Munday, P.L. Interactive effects of elevated temperature and CO_2 on foraging behavior of juvenile coral reef fish. *J. Exp. Mar. Biol. Ecol.* **2012**, *412*, 46–51.
2. Ferrari, M.C.O.; McCormick, M.I.; Munday, P.L.; Meekan, M.G.; Dixson, D.L.; Lönnstedt, O.; Chivers, D.P. Effects of ocean acidification on visual risk assessment in coral reef fishes. *Func. Ecol*. **2012**, *26*, 553–558.
3. Cripps, I.L.; Munday, P.L.; McCormick, M.I. Ocean acidification affects prey detection by a predatory reef fish. *PLoS ONE* **2011**, *6*, e22736.
4. Munday, P.L.; Pratchett, M.S.; Dixson, D.L.; Donelson, J.M.; Endo, G.G.; Reynolds, A.D.; Knuckey, R. Elevated CO_2 affects the behavior of an ecologically and economically important coral reef fish. *Mar. Biol*. **2013**, *160*, 2137–44.
5. Munday, P.L.; McCormick, M.I.; Meekan, M.; Dixson, D.L.; Watson, S.A.; Chivers, D.P.; Ferrari, M.C. Selective mortality associated with variation in CO2 tolerance in a marine fish. *Ocean Acidif.* **2012**, *1*, 1–5.
6. Munday, P.L.; Cheal, A.J.; Dixson, D.L.; Rummer, J.L.; Fabricius, K.E. Behavioural impairment in reef fishes caused by ocean acidification at CO_2 seeps. *Nat. Clim. Chang.* **2012**, *4*, 487–492.
7. Ferrari, M.C.; Manassa. R.P.; Dixson, D.L.; Munday, P.L.; McCormick, M.I.; Meekan, M.G.; Sih, A.; Chivers, D.P. Effects of ocean acidification on learning in coral reef fishes. *PLoS ONE* **2012**, 7, e31478.
8. Ferrari, M.C.; Dixson, D.L.; Munday, P.L.; McCormick, M.I.; Meekan, M.G.; Sih, A.; Chivers, D.P. Intrageneric variation in antipredator responses of coral reef fishes affected by ocean acidification: Implications for climate change projections on marine communities. *Glob. Chang. Biol*. **2011**, *17*, 2980–2986.
9. Allan, B.J.; Domenici, P.; McCormick, M.I.; Watson, S.A.; Munday, P.L. Elevated CO_2 affects predator-prey interactions through altered performance. *PLoS ONE* **2013**, *8*, e58520.
10. Allan, B.J.; Miller, G.M.; McCormick, M.I.; Domenici, P.; Munday, P.L. Parental effects improve escape performance of juvenile reef fish in a high-CO_2 world. *Proc. R. Soc. B* **2012**, *281*, 2013–2021.
11. Chivers, D.P.; McCormick, M.I.; Nilsson, G.E.; Munday, P.L.; Watson, S.A.; Meekan, M.G.; Mitchell, M.D.; Corkill, K.C.; Ferrari, M.C. Impaired learning of predators and lower prey survival under elevated CO2: A consequence of neurotransmitter interference. *Glob. Chang. Biol*. **2014**, *20*, 515–522.
12. Heinrich, D.D.; Watson, S.A.; Rummer, J.L.; Brandl, S.J.; Simpfendorfer, C.A.; Heupel, M.R.; Munday, P.L. Foraging behaviour of the epaulette shark *Hemiscyllium ocellatum* is not affected by elevated CO_2. *ICES J. Mar. Sci*. **2015**, doi:10.1093/icesjms/fsv085.
13. Munday, P.L.; Donelson, J.M.; Dixson, D.L.; Endo, G.G. Effects of ocean acidification on the early life history of a tropical marine fish. *Proc. R. Soc. B.* **2009**, *276*, 3275–3283.
14. Munday, P.L.; Gagliano. M.; Donelson, J.M.; Dixson, D.L.; Thorrold, S.R. Ocean acidification does not affect the early life history development of a tropical marine fish. *Mar. Ecol. Prog. Ser.* **2011**, *423*, 211–221.
15. Munday, P.L.; Hernaman, V.; Dixson, D.L.; Thorrold, S.R. Effect of ocean acidification on otolith development in larvae of a tropical marine fish. *Biogeosciences* **2011**, *8*, 1631–1641.
16. Miller, G.M.; Watson, S.A.; Donelson, J.M.; McCormick, M.I.; Munday, P.L. Parental environment mediates impacts of increased carbon dioxide on a coral reef fish. *Nat. Clim. Chang.* **2012**, *2*, 858–861.
17. Ferrari, M.; Munday, P.L.; Rummer, J.L.; McCormick, M.I.; Corkill, K.; Watson, S.A.; Allan, B.J.; Meekan, M.G.; Chivers, D.P. Interactive effects of ocean acidification and rising sea temperatures alter predation rate and predator selectivity in reef fish communities. *Glob. Chang. Biol.* **2015**, *21*, 1848–1855.
18. Couturier, C.S.; Stecyk, J.A.W.; Rummer, J.L.; Munday, P.L.; Nilsson, G.E. Species-specific effects of near-future CO_2 on the respiratory performance of two tropical prey fish and their predator. *Com. Biochem. Physiol*. **2013**, *166*, 482–489.
19. Rummer, J.L.; Stecyk, J.A.; Couturier, C.S.; Watson, S.A.; Nilsson, G.E.; Munday, P.L. Elevated CO_2 enhances aerobic scope of a coral reef fish. *Conserv. Physiol.* **2013**, *1*, cot023.
20. Heinrich, D.D.; Rummer, J.L.; Morash, A.J.; Watson, S.A.; Simpfendorfer, C.A.; Heupel, M.R.; Munday, P.L. A product of its environment: The epaulette shark (*Hemiscyllium ocellatum*) exhibits physiological tolerance to elevated environmental CO_2. *Conserv. Physiol*. **2014**, *2*, cou047.
21. Munday, P.L.; Crawley, N.E.; Nilsson, G.E. Interacting effects of elevated temperature and ocean acidification on the aerobic performance of coral reef fishes. *Mar. Ecol. Prog. Ser.* **2009**, *388*, 235–242.
22. Miller, G.M.; Watson, S.A.; McCormick, M.I.; Munday, P.L. Increased CO_2 stimulates reproduction in a coral reef fish. *Glob. Chang. Biol.* **2013**, *19*, 3037–3045.

23. Simpson, S.D.; Munday, P.L.; Wittenrich, M.L.; Manassa, R.; Dixson, D.L.; Gagliano, M.; Yan, H.Y. Ocean acidification erodes crucial auditory behaviour in a marine fish. *Biol. Lett*. **2011**, *7*, 917–920.
24. Devine, B.M.; Munday, P.L. Habitat preferences of coral-associated fishes are altered by short-term exposure to elevated CO_2. *Mar. Biol.* **2013**, *160*, 1955–1962.
25. Nilsson, G.E.; Dixson, D.L.; Domenici, P.; McCormick, M.I.; Sorensen, C.; Watson, S.-A.; Munday, P.L. Near-future carbon dioxide levels alter fish behaviour by interfering with neurotransmitter function. *Nat. Clim. Chang*. **2012**, *2*, 201–204.
26. Domenici, P.; Allan, B.J.; Watson, S.A.; McCormick, M.I.; Munday, P.L. Shifting from right to left: The combined effect of elevated CO_2 and temperature on behavioural lateralization in a coral reef fish. *PLoS ONE* **2014**, *31*, e87969.
27. Domenici, P.; Allan, B.; McCormick, M.I.; Munday, P.L. Elevated carbon dioxide affects behavioural lateralization in coral reef fish. *Biol. Lett*. **2012**, rsbl20110591.
28. Dixson, D.L.; Munday, P.L.; Jones, G.P. Ocean acidification disrupts the innate ability of fish to detect predator olfactory cues. *Ecol. Lett*. **2010**, *13*, 68–75.
29. Munday, P.L.; Dixson, D.L.; Donelson, J.M.; Jones, G.P.; Pratchett, M.S.; Devitsina, G.V.; Døving, K.B. Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 1848–1852.
30. Munday, P.L.; Dixson, D.L.; McCormick, M.I.; Meekan, M.; Ferrari, M.C.O.; Chivers, D.P. Replenishment of fish populations is threatened by ocean acidification. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 12930–12934.
31. Devine, B.M.; Munday, P.L.; Jones, G.P. Rising CO_2 concentrations affect settlement behaviour of larval damselfishes. *Coral Reefs*. **2012**, *31*, 229–38.
32. Devine, B.M.; Munday, P.L.; Jones, G.P. Homing ability of adult cardinalfish is affected by elevated carbon dioxide. *Oecologia* **2012**, *168*, 269–276.
33. Chung, W.S.; Marshall, N.J.; Watson, S.A.; Munday, P.L.; Nilsson, G.E. Ocean acidification slows retinal function in a damselfish through interference with GABAA receptors. *J. Exp. Biol.* **2014**, *217*, 323–326.
34. Ferrari, M.C.O.; McCormick, M.I.; Munday, P.L.; Meekan, M.G.; Dixson, D.L.; Lönnstedt, O.; Chivers, D.P. Putting prey and predator into the CO_2 equation—Qualitative and quantitative effects of ocean acidification on predator-prey interactions. *Ecol. Lett*. **2011**, *14*, 1143–1148.