Table S3. Summary of the evidence cited in support of claims that anthropogenic stressors cause blooms by the three most frequently cited sources: Purcell *et al*. [1]; Richardson *et al.* [2]; Purcell [3]

Purcell *et al*. 2007					
Stressor	Sub-type	Evidence provided	Source	Type of study	Circumstantial
Climate change	Warming	"Abundance data for *Aurelia aurita* (s. l.) and *Nemopilema nomurai* in Asia have not been analysed against climatic variables; however, temperatures in the Seto Inland Sea (*A. aurita*) and in the Yellow Sea, where blooms of *N. nomurai* may originate have increased in recent decades (Uye & Ueta, 2004; Uye, 2008)."	[4] [5]	Correlative Field Review	Yes Yes
		"Warming of the oceans may increase many populations of gelatinous species and also shift the population distributions poleward, as seems to be occurring for the ctenophore *Mnemiopsis leidyi* (Sullivan *et al*., 2001; Faase & Bayha, 2006; Hansson, 2006)."	[6] [7] [8]	Correlative field Phylogenetic Observational	No Yes Yes
		"For *Pelagia noctiluca*, a scyphomedusan lacking a benthic stage, ephyrae did not develop at 4.5°C and took twice as long to develop at 13.5° than at 19°C (Avian, 1986). In temperate scyphozoans and hydrozoans, warm temperatures increased the asexual production of buds and new jellyfish, and the ratio of jellyfish to polyps in the 3 species studied (*Aurelia labiata*, *Chrysaora quinquecirrha* and *Moerisia lyonsi*; reviewed in Purcell, 2005). Both temperature and salinity had significant effects and strong interaction (Purcell, 2007)."	[9] [10] [11]	Experimental lab Review Empirical lab	Yes No No
		Table 5 (papers cited as evidence that warming enhances jellyfish)	[4] [5] [12] [13] [14] [15] [16] [17] [18] [19]	Correlative Field Review Correlative Field Correlative Field Correlative Field Correlative Field Correlative Field Correlative Field Not accessible Correlative Field	No No Yes Yes Yes Yes Yes Yes Yes

			[10] [20] [6]	Review Correlative Field Correlative Field	No Yes No
		"Attrill *et al*., (2007) showed a significant positive correlation of nematocyst occurrence in CPR samples with decreasing pH (range 8.0 to 8.3) during 1971 to 1995, and speculated that non-calcifying gelatinous organisms might benefit from detrimental effects of low pH on calcifying organisms."	[21]	Correlative Field	No
	Acidification	"With continued climate warming, the NAO is predicted to move into a stronger positive phase (Osborn, 2004), which according to Attrill *et al*., (2007) would lead to a greater abundance of jellyfish."	[21]	Correlative Field	No
	Climate change effects on climate variability	"More food for polyps and jellyfish increases asexual production of jellyfish (e.g. Purcell *et al*., 1999a; Stibor & Tokle, 2003) and sexual reproduction (Lucas, 2001)."	[22] [23] [24]	Experimental lab Experimental lab Review	Yes Yes Yes
Eutrophication	Changes to food web structure	"Agriculture and development increased nitrate levels 10-fold in the Mar Menor, Spain, while wastewater treatment decreased phosphate by one-tenth; these conditions were associated with annual blooms of 2 rhizostome scyphomedusae, *Cotylorhiza tuberculata* and *Rhizostoma pulmo*, since 1993 (Pérez-Ruzafa *et al*., 2002)."	[25]	Correlative field	No
		"Greve & Parsons (1977) first hypothesized 2 parallel food paths in the oceans, a diatom-based path that ends with large consumers having 'high energy' requirements (e.g. whales), and a flagellate based path that ends with 'low energy' consumers (e.g. jellyfish)."	[26]	Review	No
		"High N:P ratios shift the phytoplankton community away from diatoms towards flagellates and jellyfish (Nagai, 2003)."	[27]	Correlative Field	No
		"Second, grazing by jellyfish on microzooplankton tends to be forgotten; however, it has been demonstrated for young ctenophores and jellyfish (e.g. Stoecker *et al*., 1987a,b; Olesen *et al*., 1996), which ate ciliates, but not dinoflagellates."	[28] [29] [30]	Experimental lab Experimental lab Experimental lab	Yes Yes Yes

		"Recent stable isotope analyses place *A. aurita* (s. l.*)* at a slightly higher trophic level than copepods, confirming this jellyfish's utilization of microplanktonic foods (Kohama *et al*., 2006, RD Brodeur *et al*., unpubl.). *Aurelia* spp. jellyfish, in particular, frequent highly eutrophic waters (Ishii, 2001; Mills, 2001; Nagai, 2003). A hydromedusan species, *Aglaura hemistoma*, recently was found to eat protozoans (Colin *et al*., 2005). The diets of related species (*Proboscidactyla flavicirrata*, small *Aglantha digitale)* contain mainly prey that swim by cilia (rotifers, veligers) (reviewed by Purcell & Mills, 1988); both *Aglaura* and *Aglantha* are in the same family of the Suborder Trachymedusae and feed using ciliary currents (as in Colin *et al*., 2005); thus, related species also may eat microplankton."	[31] [32] [33] [27] [34] [35]	Unavailable Correlative Field Review Correlative Field Experimental Lab Not accessible	No No No No Yes Yes
		"Fish avoid, or die in, waters of ≤2–3 mg O2 l^{-1} (reviewed in Breitburg *et al*., 2001), but many jellyfish species are tolerant of ≤1 mg O2 l^{-1} (reviewed in Purcell *et al*., 2001b). Subsequent to that review the hypoxia tolerance of several estuarine jellyfish, including *Aurelia labiata*, and ctenophores were reported to have great tolerance of low dissolved oxygen (Rutherford & Thuesen, 2005, Thuesen *et al*., 2005). Jellyfish polyps are also tolerant of low oxygen (Condon *et al*. 2001) and may find additional habitat where other epifauna is reduced in hypoxic waters (Ishii 2006). Some species of jellyfish (and planktonic ctenophores) lack a polyp stage, and those species may persist where hypoxic bottom waters prevent others with vulnerable benthic stages (Arai, 2001)."	[36] [37] [38] [39] [40]	Review Experimental lab Experimental Lab Experimental Lab Review	Yes Yes Yes Yes Yes
	Hypoxia	"Eiane *et al*., (1997, 1999) compared the optical properties of water in Norwegian fjords; jellyfish (i.e. *Periphylla periphylla*) predominate in Lurefjorden, which has much greater light absorbance than other fjords with fish."	[41] [42]	Model Mensurative Field	No No
	Turbidity	"Fishing may positively affect pelagic cnidarian and ctenophore populations by removing predators of the gelatinous species (reviewed in Purcell & Arai, 2001, Arai, 2005). Gelatinous species are eaten by many species of fish, some of which are commercially important, such as chum salmon *Onorhynchus*	[43] [44] [45] [46] [47]	Review Review Review Mensurative Field Mensurative Field	Yes Yes Yes Yes Yes

		keta, butterfish *Peprilus triacanthus*, and spiny dogfish *Squalus acanthias* (Arai 1988, 2005; Purcell & Arai, 2001). The occurrence of ctenophores in spiny dogfish stomachs was used to infer a major increase in ctenophore populations between 1981 and 2000 along the northwest Atlantic shelf (Link & Ford, 2006). Populations of other predators have been reduced at least in part because of fishing activities. Leatherback turtles *Dermochelys coriacea* have decreased dramatically in the Pacific Ocean (Spotila *et al*. 2000) and are believed to eat primarily gelatinous prey (see Arai 2005, Houghton *et al*. 2006); other sea turtle species also eat jellyfish to some degree and also are at risk."			
Overfishing	Overfishing of competitors	"Diets of forage fishes and gelatinous species overlap (Purcell & Sturdevant, 2001, R. D. Brodeur *et al*., unpubl.); therefore, reduction of forage fish can pro provide additional food for gelatinous predators. Mills (2001) suggested that increases in the siphonophore *Nanomia cara* in the Gulf of Maine could be due to reduction of zooplanktivorous fish species there. Reduction of zooplanktivorous fish populations was implicated when ctenophores and jellyfish replaced fish in the Black Sea and the Benguela Current (Shiganova, 1998; Daskalov, 2002; Oguz, 2005b; Lynam *et al*., 2006). Overharvest of mollusks and crustaceans also can lead to dramatic changes in ecosystems (in Jackson *et al*., 2001)."	[48] [33] [49] [50] [51] [52]	Mensurative Field Review Review Model Review Correlative Field	Yes Yes Yes No Yes Yes
	Removal of predators	Fishing may positively affect pelagic cnidarian and ctenophore populations by removing predators of the gelatinous species (reviewed in Purcell & Arai 2001, Arai 2005). Gelatinous species are eaten by many species of fish, some of which are commercially important, such as chum salmon *Onorhynchus keta*, butterfish *Peprilus triacanthus*, and spiny dogfish *Squalus acanthias* (Arai 1988, 2005, Purcell & Arai 2001). The ccurrence of ctenophores in spiny dogfish stomachs was used to infer a major increase in ctenophore populations between 1981 and 2000 along the northwest Atlantic shelf (Link & Ford 2006).	[43] [44] [45] [46] [47]	Review Review Review Mensurative field Mensurative field	Yes Yes Yes Yes Yes

		Populations of other predators have been reduced at least in part because of fishing activities. Leatherback turtles *Dermochelys coriacea* have decreased dramatically in the Pacific Ocean (Spotila et al. 2000) and are believed to eat primarily gelatinous prey (see Arai 2005, Houghton et al. 2006); other sea turtle species also eat jellyfish to some degree and also are at risk.			
	Fishing down food webs	"Jackson *et al*. (2001) and Daskalov *et al*. (2007) discuss how overfishing of one resource after another, in combination with other ecosystem damage, may lead to greater jellyfish and ctenophore populations."	[53] [54]	Review Mensurative Field	Yes No
Richardson *et al*. 2009					
Stressor	Sub-type	Evidence provided	Source	Type of study	Circumstantial
Climate change	Warming	"Gibbons and Richardson (2009) showed that variations in jellyfish abundance over 50 years in the oceanic North Atlantic are temperature dependent, with more jellyfish occurring in warmer years."	[55]	Correlative Field	Yes
		"Attrill *et al*. (2007) found that jellyfish in the North Sea were positively related to the NAO phase, and predicted that, because some climate models project an increased frequency of positive NAO conditions, jellyfish might also increase."	[21]	Correlative Field	No
Eutrophication	Changes to food web structure	"Coastal eutrophication encourages phytoplankton blooms that can ultimately lead to jellyfish outbreaks (Purcell *et al*., 2001)."	[36]	Review	No
		"It has been hypothesised that such a food web supports fewer fish, marine mammals, turtles and seabirds because of the smaller average food size and longer food chain (Cushing, 1989), and is more favourable for jellyfish than for fish (Parsons & Lalli, 2002)."	[56]	Review	No
		"Jellyfish can survive in such environments for many reasons (Table 1), including their ability to feed on a range of prey, including protists (Malej *et al*., 2007) such as flagellates (Colin *et al*., 2005; Sullivan & Gifford, 2004), and will thrive given the high total amount of food available."	[57] [34] [58]	Experimental Field Experimental Lab Experimental Lab	Yes Yes Yes
		"The ctenophore *Mnemiopsis leidyi* can even benefit from enhanced feeding success in low-oxygen environments because	[59]	Experimental Lab	No

		its less-tolerant prey (copepods) are more vulnerable to predation (Decker *et al*., 2004)."			
	Hypoxia	"Such 'dead zones' are thought to favour jellyfish (Graham, 2001) because of their lower oxygen and food demands compared with those of commercially valuable fish and shellfish."	[60]	Correlative Field	Yes
		(From Table 1) "Jellyfish and their polyps tolerate hypoxia (Purcell *et al*. 2001) and some species benefit from enhanced feeding rates (Decker *et al*., 2004)."	[36]	Review	Yes
		"Continue to grow in hypoxic environments (Grove & Breitburg, 2005), such as anoxic dead zones, where few jellyfish predators survive."	[61]	Experimental lab	Yes
	Turbidity	"… and fish are also predators of jellyfish, with benthic and reef fish species ingesting polyps, and pelagic fish species eating ephyrae and small individuals (Purcell & Arai, 2001)."	[43]	Review	Yes
		"Enables jellyfish to outcompete some fish in murky coastal water (Eiane *et al*. 1999)."	[42]	Mensurative Field	No
Overfishing	Overfishing of predators	"For example, in the productive northern Benguela upwelling system off the coast of Namibia, intense fishing has decimated sardine stocks, and this once-productive fisheries system is now dominated by jellyfish such as *Chrysaora* (Lynam *et al*., 2006). It is likely that the collapse of the sardine stocks lowered the predation pressure on jellyfish and increased their available food resources (Bakun & Weeks, 2004; Bakun & Weeks, 2006)."	[52] [62] [63]	Correlative Field Unsupported Review	No No No
		"Many fish compete for the same zooplankton prey as jellyfish (Purcell & Arai, 2001)…"	[43]	Review	Yes
	Overfishing of competitors	(Box 2) "When translocated ctenophores exploded in abundance following the anchovy collapse in the Black Sea (Shiganova, 1998), there was no obvious replacement. A similar episode of anchovy collapse and ctenophore explosion occurred in the Caspian Sea (Daslalov *et al*., 2007) and, following a similar general pattern, there was a decade-long increase in jellyfish abundance in the Bering Sea (Brodeur *et al*., 2008) following a lasting decline in herring abundance (Donnelly *et al*., 2003)."	[49] [54] [16]	Review Mensurative field Correlative field	No No No

Artificial structures		"Although direct evidence to support this is scant, it has been demonstrated off the coast of Taiwan (Lo *et al*., 2008) in association with mariculture operations. Further, Graham (2001) asserts that the petroleum platforms in the Gulf of Mexico, which extend from the seafloor to the surface, provide polyps with the opportunity to attach at a depth where physical conditions are ideal for growth."	[64] [60]	Correlative Field Correlative Field	No Yes
Purcell 2012					
Stressor	Sub-type	Evidence provided	Source	Type of study	Circumstantial
Climate change	Warming	"In agreement with previous studies, scyphomedusae that were more abundant included *C. quinquecirrha* in Chesapeake Bay (Decker *et al*., 2007) and *A. aurita* and *Cyanea* spp. in the North Sea west of Denmark (Lynam *et al*., 2010). *A. aurita* and *Cyanea* spp. also were more abundant during warm years in the southern part of the North Sea and in the Irish Sea (Lynam *et al*., 2010, 2011). High abundances of *Pelagia noctiluca*, *A. aurita*, and *Rhizostoma pulmo* in 2003 coincided with exceptionally warm temperatures and low river flow in the Northern Adriatic Sea (Kogovšek *et al*., 2010). Pacific black sea turtle landings were high during every El Niño and warm event between 1970 and 1988 when they foraged on *Chrysaora plocamia* medusae in southern Peru (Quiñones *et al*., 2010). Several holoplanktonic jelly species also have been most abundant in warm, high-salinity conditions in the Mediterranean Sea (Molinero *et al*., 2005, 2008)."	[65] [66] [67] [68] [69] [13] [70]	Model Correlative Field Correlative Field Correlative Field Correlative Field Correlative Field Model	No Yes No Yes Yes Yes Yes
		Supplemental Table 2 – papers reporting increase in jellyfish associated with warm conditions (excluding those already reported in row above)	[4] [12] [71] [72] [73] Lynam *et al*., (2010a) Lynam *et al*., (2010b) [14]	Correlative Field Correlative Field Correlative Field Correlative Field Correlative Field Reference details not provided by author Reference details not provided by author Correlative Field	No Yes Yes Yes Yes Yes

			[15] [16] [5] [74] [75] [17] [18] [19] [10] [76] [20] [77] [55] [78] [6] [79]	Correlative Field Correlative Field Review Review Correlative Field Correlative Field Unavailable Correlative Field Review Mensurative Field Mensurative Field Correlative Field Correlative Field Correlative Field Correlative Field Model	Yes Yes No No Yes Yes Yes No Yes Yes No No No No No
Eutrophication	Changes to food web structure	"Accumulating evidence suggests that high N:P ratios shift the phytoplankton community from a diatom to a flagellate-based food web, which may favor jelly blooms (Purcell *et al*. 2007)."	[1]	Review	No
	Hypoxia	"Fish avoid or die in waters of ≤2–3 mg O2 per liter, but many jellies are tolerant of ≤1 mg O2 per liter (Purcell *et al*., 2007). Additional evidence confirms the tolerance of jellies to hypoxic conditions and defines limitations to their use of hypoxic habitats. The swimming bell contraction rate of *A. aurita* medusae was constant over the DO levels from 1.0 to 5.8 mg O2 per liter; by contrast, gill ventilation rates and swimming speeds in Spanish mackerel decreased at ≤4 mg O2 per liter, indicating stress (Shoji *et al*., 2005). Feeding rates on fish larvae increased at low DO for the medusae but decreased for the fish. In Hiroshima Bay, the greatest abundances of these medusae were where bottom-layer DO concentrations were the lowest (2–3 mg O2 per liter), suggesting no adverse effects (Shoji *et al*., 2010). Settlement of *A. aurita* planulae was quickest and highest in the lowest DO concentration tested (0.2 mg O2 per liter); however, the polyps survived <7 days. At 2 mg O2 per liter, however,	[1] [80] [81] [82] [83]	Review Experimental Lab Correlative Field Mensurative Field Correlative Field	Yes No Yes Yes Yes

		budding of new polyps was less than at 4.5 mg O2 per liter, and no strobilation occurred (Ishii *et al*. 2008). In Tokyo Bay, one of the most eutrophic in Japan, most polyps were ≤2 m above the bottom where mussel biomass was lowest (Ishii & Katsukoshi, 2010)."			
		"Large (but not small) *M. leidyi* ctenophores had lower growth and egg production in low DO concentrations (1.5 and 2.5 mg O_2 per liter) than in saturated DO, but *Chrysaora quinquecirrha* medusae growth was unaffected (Grove & Breitburg, 2005). Clearance rates of *M. leidyi* on fish eggs and larvae were the same at low and high DO concentrations (1.5 and 7 mg O2 per liter), and ctenophore densities were high in the bottom layer even in low DO (Kolesar *et al*., 2010)."	[61] [84]	Experimental Lab Experimental Lab	No Yes
	Turbidity	"Light penetration in Norwegian fjords with extremely high abundances of the mesopelagic medusa *Periphylla periphylla* is lower than in fjords with two species of visual zooplanktivorous fish (Eiane *et al*., 1999; Sørnes *et al*., 2007; Asknes *et al*., 2009)."	[42] [85] [86]	Mensurative Field Mensurative Field Correlative Field	Yes Yes Yes
	Direct uptake of nutrients	"By contrast, zooxanthellae in medusae can assimilate dissolved inorganic C (DIC) from the water column, and species like C*assiopea* spp. can utilize nutrient pools that are unavailable to azooxanthellate species. *Cassiopea* sp. medusae actively extracted and took up inorganic nutrients from the sediment (Jantzen *et al*., 2010) and occurred in high abundances (31 medusae m−2) in tropical habitats (Niggl & Wild, 2010). In Bermuda, the sizes and densities of *Cassiopea* spp. medusae and the nutrient concentrations were greater where human densities were high than where they were low (Stoner *et al*., 2011)."	[87] [88]	Experimental Lab Correlative Field	Yes No
Overfishing	Overfishing of predators	"Other predators of jellies include 124 species of fish, including commercial species, and 34 other animals (Purcell & Arai, 2001; Arai 2005; see also Pauly *et al*., 2009)."	[43] [44] [89]	Review Review Review	Yes Yes Yes

	Overfishing of competitors	"When the populations of forage fish are reduced by fishing, zooplanktivorous jellies have flourished, presumably owing to reduced competition for food, as for *Mnemiopsis leidyi* ctenophores in the Black Sea (Daskalov *et al*., 2007). This potential link was suggested many years ago (Möller, 1980), but competition has been tested directly only once to my knowledge (i.e., for larval herring; Purcell & Grover, 1990).The diets of jelly and forage fish species are similar, with overlaps ranging from 0.2% to 73.4% (Purcell & Sturdevant, 2001; Brodeur *et al*., 2008b) and from 84% to 89% for *M. leidyi* and Caspian anchovy (Darvishi *et al*., 2004)."	[54] [90] [91] [48] [92] [93]	Mensurative Field Not available Mensurative Field Mensurative Field Mensurative Field Mensurative Field	No Yes Yes Yes Yes
		"The inverse biomasses of *M. leidyi* and fishes are striking in the southern Black Sea, where anchovy (potential competitor) catches in 1989 were 20% of those in 1988 and mackerel (potential predator) catches in 1991 were 20% of those in 1990; meanwhile, the ctenophore live biomass surged in 1990 (Mutlu, 2009)."	[94]	Mensurative Field	Yes
Artificial structures		Planulae of six scyphozoan species preferentially settled on artificial substrates (Holst & Jarms, 2007; Hoover & Purcell, 2009);	[95] [96]	Experimental Lab Experimental Lab	Yes Yes
		In addition to surfaces for polyps, harbors and aquaculture lagoons provide calm, eutrophic water that retain jellies (Lo *et al*., 2008). Early and continuing human modification of shorelines also included structures to protect against erosion, retain sediments, and provide transportation (Bulleri & Chapman, 2010) that also host these populations (Willcox *et al*., 2008).	[64] [97]	Correlative Field Experimental Field	Yes Yes

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