Chapter 6
Coral and Cnidarian Welfare in a Changing Sea

Ernesto Weil, Adriana Weil-Allen, and Alejandro Weil

Abstract Coral reefs worldwide are currently threatened by anthropogenic Global Climate Change (GCC) and local environmental degradation and, unequivocally, need protection. Coral reefs constitute one of the oldest, most diverse, and important marine communities. They are mainly formed by tiny, primitive, calcifying, Cnidarian invertebrates, the scleractinian corals, and provide substantial ecological services to other marine communities, coastal protection, food, and economic and social benefits to humans. Cnidarians and other reef invertebrates are exploited by the marine aquarium trade, but their capture, transport, and maintenance in captivity (for research or exhibition) are not regulated by any welfare provisions. Traditional principles of animal welfare are not easily applicable to wildlife, much less to simpler organisms such as cnidarians, but arguments could be made since scleractinian corals, as most invertebrates, are highly sensitive to changes in environmental conditions and display stressful physiological and/or behavioral responses. Higher than normal temperatures, for example, elicit the expulsion of their algal symbionts (i.e., bleaching), increase mucus production, and/or adjust metabolic pathways and physiological functions, to enhance survivorship. Global Climate Change is stressing marine animals and is threatening the health of the oceans. Welfare considerations to at least those cnidarians that function as foundation or keystone species could add up and help protect these communities from further decline. How we approach the solutions to the problems generated by the increasing human needs must include a change in attitude, from being mostly "reactive," which is costly and difficult, to being more preventive/proactive. We believe that approaches combining both conservation and welfare principles could be developed and implemented to increase the survivorship and good health of ecologically and economically important marine invertebrates. Besides convincing scientists, and mostly animal welfare scientists, that corals should be included in our "circle of compassion," the most essential

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component for this to work is education. An educated population who understand the importance of our interaction with the natural world will help to institutionalize welfare principles to increase protection and to reduce, or stop, the current declining trends of coral reefs and other marine communities. This would enhance the possibilities of a successful recovery of these important communities so we can continue using them in a sustainable way and, more importantly, preserve them for future generations.

6.1 Introduction

Since the appearance of humans, we have been interacting with other animal and plant species in many different ways (parasite-host, predator-prey, competition, harvesters and domestication, etc.). Animal welfare has been a concern for thousands of years, for example, during the long process of domestication, different cultures and religions developed their own regulations for the animals they deemed important (Adams and Larson 2011). The ethical aspect about the quality of life (their well-being) of animals, however, has only been emphasized within the past century and has become the subject of public scrutiny and controversy. The investigation of animal welfare using rigorous scientific methods is a relatively recent development. The Animal Protection Act (1822) in the United Kingdom was the first national law developed to protect farm animals. It was followed by the Cruelty to Animals Act (1866), the first national bill to regulate animal experimentation (Fraser et al. 1997). Numerous countries in Europe followed with regulations regarding research with animals. The United States reacted almost 100 years later with the Animal Welfare Act in 1966, which is the only Federal law that regulates the treatment of animals in farms, research, exhibition, transport, and by dealers (Stevens 1990; Harvey-Clark 2007).

There is no universal definition for animal welfare, as it can vary depending on cultural, religious, social, or scientific context. However, three main aspects and ethical concerns are commonly expressed regarding the quality of life of an animal: (1) their physical health, (2) their subjective state, and (3) their natural life. At least two of these are applicable to invertebrates, but there are limitations on how to assess them and interpret the results and their validity. How to differentiate between fear vs. excitement and pain vs. stress, for example, or establish the animal's mental state can be harder in vertebrates and may not apply to invertebrates. The third state considered is their natural life, which assesses the ability of animals to perform their natural functions, behaviors, and capabilities in captivity and in their natural habitat (Fraser et al. 1997). The American Veterinary Medical Association (AVMA) regards animal welfare as a human responsibility that requires analyzing how animals cope with their living conditions, which includes and considers all aspects of animal well-being (housing, management, nutrition, disease prevention and treatment, responsible care, humane handling, and, when necessary, humane euthanasia). The AVMA defines animal welfare as: "An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behavior, and if it is not suffering from unpleasant states such as pain, fear, and distress" (https://www.avma.org/public/AnimalWelfare/Pages/default.aspx).

Most of the abovementioned considerations, however, are exclusively applied to domesticated animals, which include mostly mammals and birds. When dealing with wildlife species and invertebrates in particular, applying the AVMA principles is difficult. There are several limitations and information gaps; for example, information on their biology, ecology, physiology, behavior, and even geographic distribution is usually limited at best, and direct observations and/or sample collection are difficult and costly. Wildlife welfare is mostly based and categorized within ecological and conservation measures rather than ethical/humanitarian considerations, and legislation efforts are usually in response to species' drastic population declines due to environmental degradation, habitat destruction, and/or overharvesting and aimed at the conservation and survival of the species (Tables 6.1 and 6.2, Fig. 6.1)

Table 6.1 Marine invertebrates (25 scleractinian corals and two abalones) that are either threatened (T) or endangered (E) according to ESA, their geographic distribution, and drivers responsible for the significant population declines (signs)

Phylum	Species	Dis	Status	Drivers
Cnidaria	*Acropora palmata*	CA	T	High temp./disease/habitat loss
Cnidaria	*Acropora cervicornis*	CA	T	High temp./disease/habitat loss
Cnidaria	*Orbicella annularis*	CA	T	High temp./disease
Cnidaria	*Orbicella faveolata*	CA	T	High temp./disease
Cnidaria	*Orbicella franksi*	CA	T	High temp./disease
Cnidaria	*Dendrogyra cylindrus*	CA	T	High temp./disease
Cnidaria	*Mycetophyllia ferox*	CA	T	High temp./disease
Cnidaria	*Acropora globiceps*	PA	T	High temp./disease/predation
Cnidaria	*Acropora jacquelineae*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Acropora lokani*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Acropora pharaonis*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Acropora rudis*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Acropora speciosa*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Acropora retusa*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Acropora tenella*	PA	T	High temp./disease/predation/habitat loss
Cnidaria	*Anacropora spinosa*	PA	T	High temp./disease
Cnidaria	*Cantharellus noumeae*	PA	E	Mining/sedimentation/habitat loss
Cnidaria	*Euphyllia paradivisa*	PA	T	Harvesting/ High temp/disease
Cnidaria	*Montipora australiensis*	PA	T	High temp./predation/disease
Cnidaria	*Pavona diffluens*	PA	T	High temp./disease
Cnidaria	*Porites napopora*	PA	T	Harvesting/disease
Cnidaria	*Seriatopora aculeata*	PA	T	High temp./disease
Cnidaria	*Siderastrea glynni*	PA	E	High temp./disease/coastal development
Cnidaria	*Tubastraea floreana*	PA	E	Possibly high temperatures
Cnidaria	*Isopora crateriformis*	PA	T	High temp./predation/disease
Mollusca	*Haliotis cracherodii*	NPA	E	Overharvesting
Mollusca	*Haliotis sorenseni*	NPA	E	Overharvesting

CA Caribbean, *PA* Pacific, *NPA* Northern Pacific

Table 6.2 Invertebrates "protected" by the CITES agreement

Phylum	Class	Number of species on list
Mollusca	Bivalvia	31
Mollusca	Cephalopoda	1
Mollusca	Gastropoda	4
Cnidaria	Anthozoa	All (over 6000)
Cnidaria	Hydrozoa	All (over 3800)
Echinodermata	Holothuroidea	1

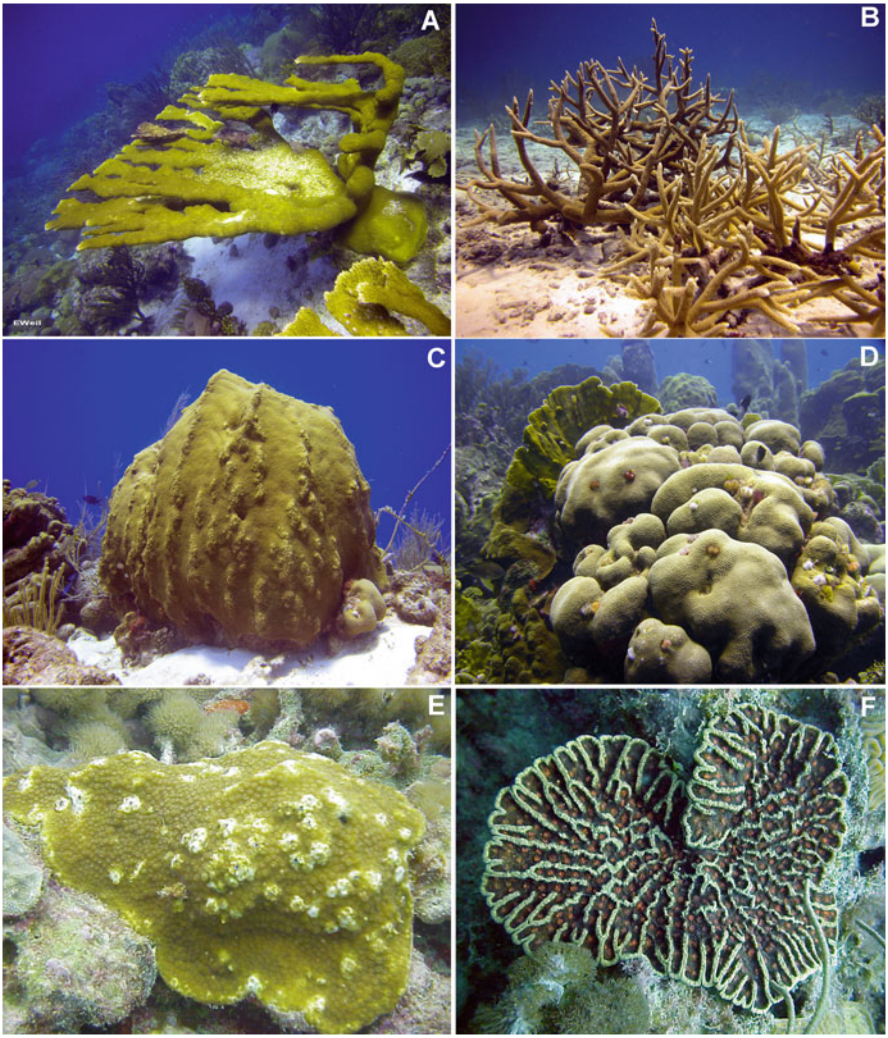

Fig. 6.1 Caribbean scleractinian corals listed as threatened and/or endangered by ESA. (**a**) *Acropora palmata*; (**b**) *A. cervicornis*; (**c**) *Orbicella faveolata*; (**d**) *O. annularis*; (**e**) *O. franksi*; (**f**) *Mycetophyllia ferox* (Photos E. Weil). Caribbean coral *Dendrogyra cylindrus* (**g**) and abalone species from the Northeastern Pacific, *Haliotis cracherodii* (**h**) and *Haliotis sorenseni* (**i**) listed as threatened species by ESA (Photos a to g by e. Weil; photos h and i from CITES webpage)

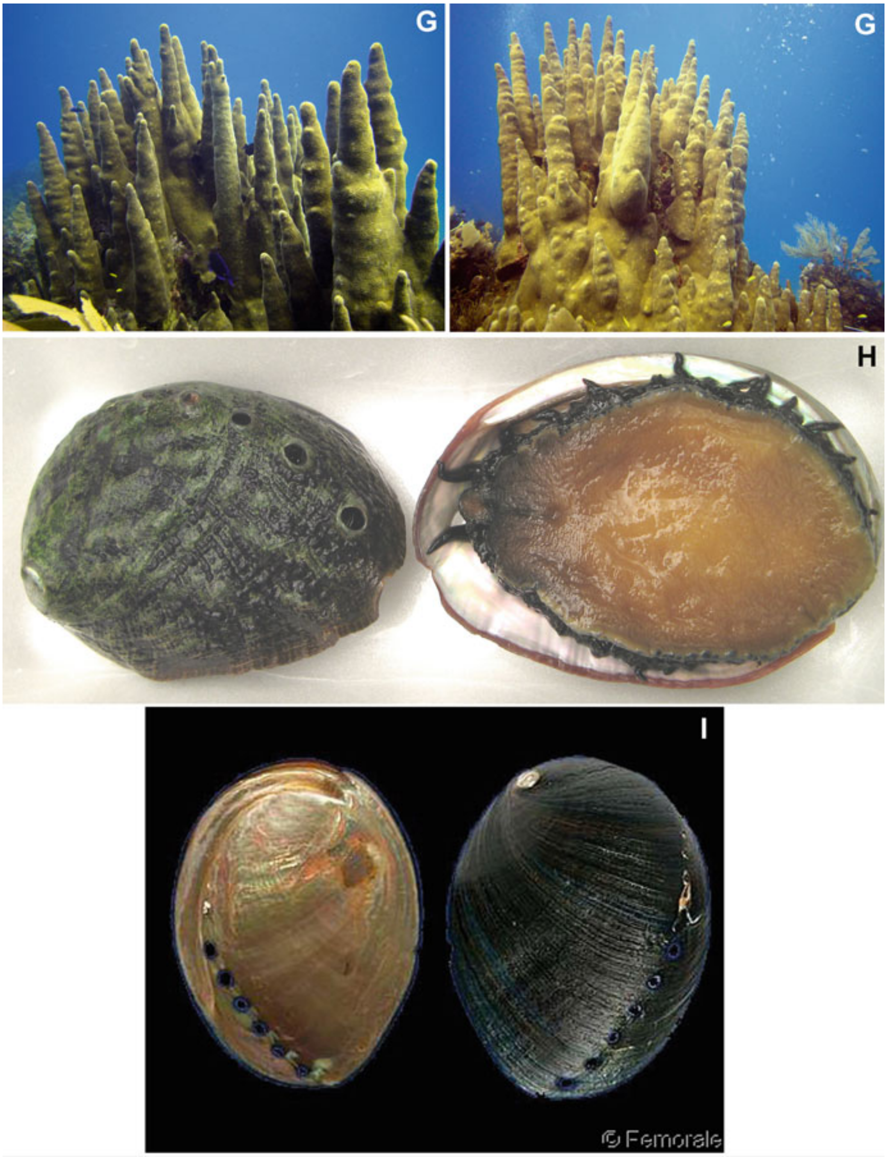

Fig. 6.1 (continued)

(Paquet and Darimont 2010). This gap between ecology and ethical/humanitarian principles should be eliminated or at least narrowed as to include welfare principles into any wildlife conservation and management plans, which will at least improve survivorship of the species involved.

Most conservation scientists now agree that human-induced destruction and deterioration of wildlife habitats and environments are characterized by a general disregard for the affected organisms living in those habitats, more so if they are invertebrates, which mostly result from lack of education and inadequate scientific and ethical guidance. Current anthropogenic-induced environmental and habitat deterioration is causing physiological stress and possibly "pain" to many important marine invertebrate species through thermal anomalies, floods, chemical imbalances (i.e., insecticides, fertilizers, hormones, untreated sewage, ocean acidification), displacement, starvation, physical injury, and disease, all traits included in the AVMA principles for animal welfare (Harvell et al. 2002; Bekoff 2002; Goodall and Bekoff 2002; Bradshaw et al. 2005; Bruno et al. 2007; Hoegh-Guldberg et al. 2007; van Oppen and Lough 2009; Paquet and Darimont 2010; Dubinsky and Stambler 2011; Horvath et al. 2013; Woodley et al. 2016; Weil et al. 2017).

The great majority of multicellular animals living on the planet are invertebrates. Many are parasites or pests, but a wide variety provide important ecological services at many different levels, and humans use them for food, agriculture, and commercial products, as pets and in research. However, contrary to their vertebrate counterparts, there are hardly any specific welfare considerations or laws to protect at least those beneficial invertebrates. With the exception of cephalopods, which are extensively used in research, marine invertebrates are only "protected" by local/international, ecologically based conservation regulations (i.e., marine protected areas, the Endangered Species Act, the IUCN Global Red List and Species Program, etc.), which mostly protect threatened/endangered species and their critical habitats to enhance survivorship. The Convention on International Trade in Endangered Species (CITES) is supposed to control collection, movement, and trade of wild species across international borders.

6.2 Cnidarian Welfare

Coral reefs constitute one of the oldest, most diverse, and important marine communities. They are mainly formed by the scleractinian corals, a group of tiny, primitive, simple, calcifying invertebrate organisms in the phylum Cnidaria (Coelenterates), which provide substantial ecological services to other marine communities, coastal protection, food, and economic and social benefits to humans. The colorful Cnidarians are known as the "flowers of the sea" because of their shapes and bright colors. One of the oldest animal groups on the planet (at least 490 million years) survived four of the major mass extinction events in the history of life (Wood 1999; Park et al. 2012). It is the only metazoan group with true radial symmetry and the first with organized tissue layers, nerve networks, and a gastrovascular cavity (coelenteron), an adaptation that allows internal digestion of large prey. Capture of large prey is possible due to their unique, large stinging cells called cnidocytes (nematocysts), a diagnostic trait for the phylum that packs a coiled thread with a harpoon-like tip and potent neurotoxins under hydrostatic pressure. They are also used for defense and protection. Cnidaria is considered the sister group to the bilateria (bilateral symmetry) and comprises two reciprocally monophyletic clades with six classes including over 10,000 of mostly marine species distributed across all oceans and depths. They are solitary or colonial (modular), sessile, and/or free-living animals (alternant generations), reproduce both asexually and sexually, and are important members of most marine communities. Several groups within the Cnidaria are ecologically very important: the hard corals (scleractinian), milleporids (hydrocorals), and octocorals (Alcionacea, octocorallia), for example, comprise foundation species that build complex, stable, three-dimensional, hard structures of calcium carbonate and/or protein (gorgonin) that provide habitat, energy, and resources to thousands of other species across tropical and temperate marine habitats and down to 6000 m deep. They protect coastal areas and are important touristic, research, and educational assets (Kellert 1993; Veron et al. 2009; Dubinsky and Stambler 2011; Horvath et al. 2013; Birkeland 2015; Hubbard et al. 2016).

Despite their ecological/economic importance, no specific welfare regulations are in place for cnidarians or any other important invertebrates. They are under some level of protection by the Endangered Species Act (ESA) and the Convention on International Trade in Endangered Species (CITES), which are based on ecological and economic rather than ethical or humanitarian arguments (Jones et al. 2017). Most of the American Veterinary Medical Association (AVMA) principles do not apply to the great majority of marine invertebrates, and assumptions that invertebrates do not experience pain and/or stress (Elwood 2019), while lacking the capacity for higher order cognitive functions, are usually used as justification for the lack of welfare consideration for invertebrates in general (Horvath et al. 2013). This is somehow reinforced by the some negative view and perception of many invertebrates by the public. Many people express feelings of aversion or fear toward most invertebrates due to concerns of disease (carriers, vectors), poisonous and painful stings, pests that eat people's food, or by being "unattractive" animals among others (Horvath et al. 2013). Even the scientific community has minimal ethical concerns for invertebrates they use in research, making them easier to use as lab models for many experiments instead of vertebrate subjects, which receive far greater ethical considerations (Vitale and Pollo 2018, Chap. 2; Kellert 1993; Mather 2001; Manev and Dimitrijevic 2004; Mather and Anderson 2007; Andrews et al. 2011; Horvath et al. 2013). This is slowly changing but unfortunately only for a few species, like cephalopods and some crustaceans. After extensive research in physiological, cellular processes, neuronal and behavioral responses, and stress resistance to environmental changes, results indicate that these invertebrates may be just as able as vertebrates to experience pain and stress and display comparable cognitive capacities (Horvath et al. 2013; Mather and Anderson 2007; Mather et al. 2010; Elwood et al. 2009; Horvath et al. 2013). To this day, cephalopods are the only invertebrates that have been included in welfare legislations related to the protection of animals used for scientific purposes (Ponte et al. 2018, Chap. 9); European Union Directive 2010/63/UE; Australian Code for Research Animals; Andrews et al. 2011). The remaining invertebrates used in research not included or not having been studied for adequate protection or welfare policies remain unprotected and to the discretion of the collectors, transporters, and scientists involved. On the other hand, thousands of Cnidarian species and other marine invertebrates are captured, transported, and sold at pet shops every year or used in large aquariums and exhibitions, with no ethical considerations for how these animals must be treated in each one of these steps, with a high mortality rate (Jones et al. 2017).

Scientific-based wildlife conservation seems to be a good approach to draw attention to invertebrate welfare, especially to those species and groups that are foundation species (such as scleractinian corals, octocorals, oysters, sponges, etc.) providing habitat, refuge, food, and other important ecological services and benefits to humans. There is no one global organization/association or law that protects all aspects of wild animals and plants, but there are a few local government regulations aimed at the protection of individual species and/or their essential habitats and ecosystems. In the United States, a significant piece of legislation to protect wild habitats and species is The Endangered Species Act (ESA) of 1973 (NOAA). It provides for "the conservation of species that are endangered or threatened throughout all or a significant portion of their distribution range, and for the conservation of the ecosystems on which they depend." The key signs include significant population declines over their geographic distribution and loss of critical habitat. Listing species is a complicated and long task, requiring the participation of scientists and managers who have to justify the request with actual quantitative data on top of extensive qualitative observations, which requires long temporal observations and data gathering. Unfortunately temporal scales generally work against invertebrate species that are short-lived (short generation times) and have small sizes and/or small population sizes, one reason why we are losing so many species nowadays. Only 2 commercial abalones (mollusks) and 25 scleractinian corals (8 from the Caribbean and 17 from the Indo-Pacific) are listed as either threatened or endangered under the ESA (Tables 6.1 and 6.2, Fig. 6.1).

Other countries have similar legislations that have helped to establish some sort of a protection "network" with minimal "welfare" policies for wildlife (Great Britain, the European Union, China). One of the very few global approaches to conservation/protection of wildlife is the IUCN Global Species Program and the IUCN Species Survival Commission, sponsored by the United Nations. Their goal is "to assess the conservation status of species, subspecies, varieties, and even selected subpopulations on a global scale" to provide information on conservation status and population distribution (densities, health conditions, etc.) in order to highlight taxa that are endangered and/or threatened with extinction and thereby promote their protection and conservation to enhance their survivorship (The IUCN Red List of Threatened Species. IUCN) (Table 6.2). In some way this program provides valuable information that is used by ESA to list species. It seems logical that principles of "animal welfare" could be included for both the IUCN and ESA to complement the other protection/conservation aspects and insure the welfare and survivorship of threatened and/or endangered species at least. Unfortunately they seem to act more as witnesses rather than guardians to animal welfare and conservation status and are more reactionary rather than advocating preventive/proactive actions.

The annual trade in wildlife animals, including invertebrates, is increasing constantly (Table 6.2 and Fig. 6.2), representing a major threat to wildlife populations, even without considering the major problem of illegal trade. The Convention on International Trade in Endangered Species (CITES) works with ESA and the IUCN

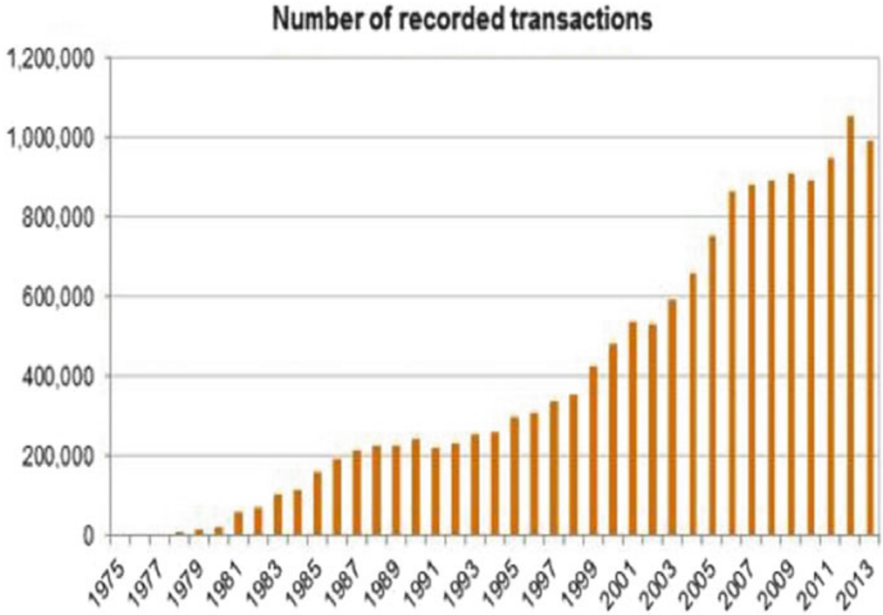

Fig. 6.2 Increment in the total number of recorded CITES transactions per year until 2013. (https://www.cites.org/)

to regulate movement and trade of wildlife. The marine aquarium trade, for example, moves thousands of marine invertebrates every year, most of these under stressful conditions that end up with high mortalities (Bruckner 2000; Tissot et al. 2010; Mason 2010; Rhyne et al. 2013). The only regulations on protection are restricted to species that are deemed threatened or endangered by the ESA and the IUCN red list or other agencies in other countries. There are roughly 5600 species of animals and 30,000 species of plants "protected" by CITES that establishes a global regulatory framework for the prevention of trade in endangered species and for the effective monitoring and regulation of trade in species that are not necessarily threatened with extinction but may become so unless trade is strictly controlled. Today, there are 183 country members that are bound by the provisions of CITES, but there is little information about enforcement of these provisions.

The CITES list includes whole groups of organisms (i.e., primates, cetaceans, sea turtles, Anthozoa), individual species or subspecies, that have regulations over their international trade only, but not their local welfare or conservation, which should be the responsibility of each member country. In principle, the CITES requirements are designed to ensure sustainable harvest; in practice, countries may be unable to make a science-based finding of no detriment because of limited resources and expertise. Therefore, CITES regulations allow an importing country to implement additional restrictions or to require additional documentation to enhance conservation of wildlife populations (Bruckner 2000; Shuman et al. 2005). However, there are no ethical considerations on how the harvest should be done with minimal distress and pain, how the invertebrates must be cared for during transportation and in confinement, or how to treat them during research activities. In general, the IUCN Global Species Program Red List, ESA, and CITES are a good start to providing a foundation for future wildlife protection efforts for invertebrates and marine invertebrates in particular. Ideally, this should be global and supported by all countries given the connectivity across marine ecosystems and not restricted to geopolitical borders since the geographic distribution of species and/or ecosystems transcends these borders. Even though protecting habitats and species is beneficial for everybody, agreements are difficult to reach in most situations due to cultural, religious, and social/political or economic differences.

These are just a few examples of how countries can agree on animal and plant welfare principles without the need for international laws and courts. Figure 6.2 shows why organizations and agreements such as CITES are needed. It shows the documented trade of flora and fauna between countries over time. The number of transactions has increased significantly over time, and while there is no guarantee that this will continue to be the case, with over a million recorded transactions in 2012, the need for clear establishment of specific animal welfare regulations is apparent. Ensuring a sustainable trade in coral reef organisms, for example, will require long-term international commitment to a policy that protects them from overharvesting and completely bans destructive harvest practices. The situation, however, is probably more critical when the illegal trade is taken into consideration.

A key first step is for exporting and importing countries to establish accurate data gathering and monitoring systems so that species-specific information is reliable. This would include the numbers of organisms captured and traded and the extent of their survival from harvest to consumer (Bruckner 2000). The only group of marine invertebrates included in the CITES list are the scleractinian corals because of their ecological and economic importance and their recent drastic decline at local and geographic scales. This is mostly due to disease outbreaks and bleaching linked to Global Climate Change, overfishing, and local anthropogenic-induced environmental deterioration (Harvell et al. 1999, 2002; Bruno and Selig 2007; Rosenberg and Loya 2004; Wilkinson 2004; Wilkinson and Souter 2008; Hoegh-Guldberg et al. 2007; Hoegh-Guldberg and Bruno 2010; Carpenter et al. 2008; Aronson et al. 2008a, b; Miller et al. 2009; Weil et al. 2009; Weil and Rogers 2011; Jackson et al. 2014; Mumby and Van Woesik 2014).

A common concern difficult to interpret when discussing invertebrate welfare is that of the cause (stimulus) of pain and suffering and the anthropomorphic interpretation of the "sensory" mechanisms and the physiological and/or behavioral response. Deciding how to interpret an invertebrate's response to noxious, stressful, or "painful" stimulus can be difficult, speculative, and highly variable across species, especially when differentiating between a nociceptive (reflexive) and pain-related (sensory and emotional) responses (Elwood 2019; Kellert 1993; Fraser et al. 1997; Elwood et al. 2009; Elwood 2011; Adamo 2012; Horvath et al. 2013). For example, interpreting the response to a "painful" stimulus when presented to an octopus will contrast significantly when applied to a coral or a sea anemone, since their sensory cells, "nerve" networks, and stimuli transduction are different. Just because the octopus can meet the criteria of sensing the stimuli, removing itself away from it and potentially learning to avoid it, does not mean that other invertebrates have the same capacity, or could not respond to it in different ways (Carere et al. 2011; Elwood 2011; Crook 2013). Evolutionarily speaking, it is logical to assume that most organisms must have the necessary receptors to "sense" changes in their surroundings (environment, predators, competitors) that could threaten their survival in order for an appropriate response to be elicited. Sensory cells and/or mechanisms associated with this are highly adaptive and surely evolved early in the history of life.

Most cnidarians (i.e., Anthozoa and Hydrozoa, 9800 species) are modular (colonial) and sessile. Modular sessile organisms had a different evolutionary history and life history traits compared to the free-living cnidarians and to non-modular, motile invertebrates. They live attached to the substratum and do not have the option of moving away from any stressful, noxious stimuli (i.e., high temperature), retracting polyps to avoid predators or expanding them to compete for substrate (Fig. 6.3). The individual modules, the polyps, have a limited number of responses to prevent/reduce injury (mortality) when threatened or when under stress by changing environmental conditions (Goffredo and Dubinsky 2017).

Can the capacity to sense and respond to stress in their way be used as arguments to provide them with welfare considerations? Cnidarians have rudimentary sensory cells capable of responding to stressful and noxious stimuli and an efficient nerve network that can transmit the stimuli bidirectionally very fast. These cells are naked (no myelin) and do not form any central nervous system. The structural array varies across classes with some showing nerve concentration that look like "ganglia." Sensory and motor "neurons" are spread throughout the individual polyps and colonies allowing for quick muscular contractions and expansions or a cascade of other adaptive responses in corals and other modular cnidarians. These colonies are formed by aggregations of thousands of individual polyps (modules) that are physiologically connected (tissues). Communication between nerve cells occurs by

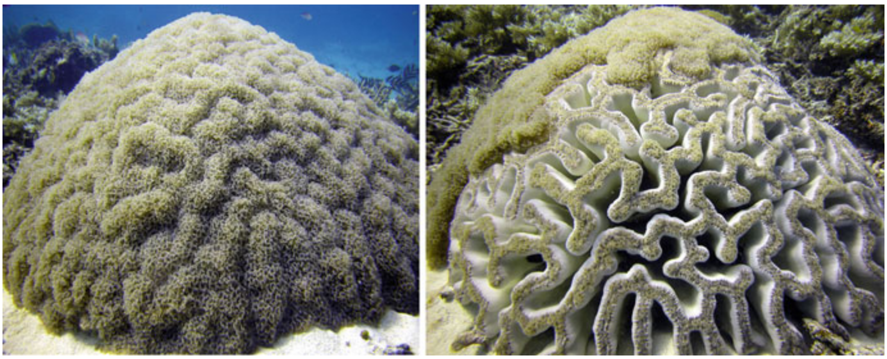

Fig. 6.3 Protection response by a coral colony. Polyps were fully exposed to gather sunlight (left), but they quickly retracted into their calices in a continuous fashion across the colony revealing a curious structure after the diver touched the lower right side. The whole process lasted less than 30 s (Photos E. Weil)

chemical synapses or gap junctions in hydrozoans, though gap junctions are not present in all groups (Galliot et al. 2009). Cnidarians have many of the same neurotransmitters that most of the more advanced metazoans have, including glutamate, GABA, and acetylcholine (Kass-Simon and Pierobon 2007).

Beside fast responses to stimulus like touch (pressure) (Fig. 6.3), Cnidarians show quick responses to changes in environmental stimuli (i.e., changing temperatures and light conditions, chemical imbalances, pH, salinity, sedimentation, etc.) that may threaten their survivorship. Some of the common visible adaptive responses include modular retraction, nematocysts discharge, polyp swelling, hyper-production of mucus, expulsion of zooxanthellae symbionts (bleaching), and immune responses like melanization (Fig. 6.4). They also experience changes in metabolic pathways and/or physiological functions when under stress (slow growth, reduced immune responses, decline in reproductive output, etc.) to distribute energy and resources to maintain basic functioning and increase survivorship (Szmant and Gassman 1990; Petes et al. 2003; Flynn and Weil 2009; Mydlarz et al. 2006, 2008; Galliot et al. 2009; Couch et al. 2013; Morgan et al. 2015; Fuess et al. 2017). The question then becomes whether this level of physiological response to environmental or anthropogenic-induced stressors is enough to consider ethical arguments to protect these organisms? Conservation measures do seem to provide some level of protection at the population and/or habitat levels, but they are only applied when there are strong indications (quantitative evidence) that population densities have declined significantly or the habitat is being destroyed.

A different situation is that of commercially important species that suffer from overharvesting (i.e., aquarium trade), and protection measures are imposed as a consequence of the lack of profitability rather than to any of the population, ecological or "welfare" principles (Horvath et al. 2013, Lafferty et al. 2015). Because natural habitat deterioration is increasing as a consequence of human activities and Global Climate Change (GCC), the scope of species conservation/protection nowadays includes the habitat(s) where the endangered/threatened species live to safeguard the very resources they need for survival. In most cases, however, the protective, conservation regulations have been applied only after drastic ecological consequences (reactive rather than preventive), such as significant population declines of foundation or keystone species, habitat quality degradation, pollution, or disease outbreaks (Gardner et al. 2003; Wilkinson 2004; Wilkinson and Souter 2008; Jackson et al. 2014; Jones et al. 2017).

Approximately 75% of the world's coral reefs are considered threatened when local threats are combined with GCC threats. One common instrument to protect marine habitats and species is the designation of Marine Protected Areas (MPAs), where humans are not allowed or their activities strictly managed to keep the communities and their environment as undisturbed as possible. There are at least 400 MPAs that include coral reefs in more than 65 countries and territories. This would be encouraging if not for the fact that only a small percentage of these (23%) are well managed with sound conservation and usage regulations and enforcement (Burke et al. 2011; Jones et al. 2017). Besides the large number of countries and important reef regions with no formal protection for their coral reef communities,

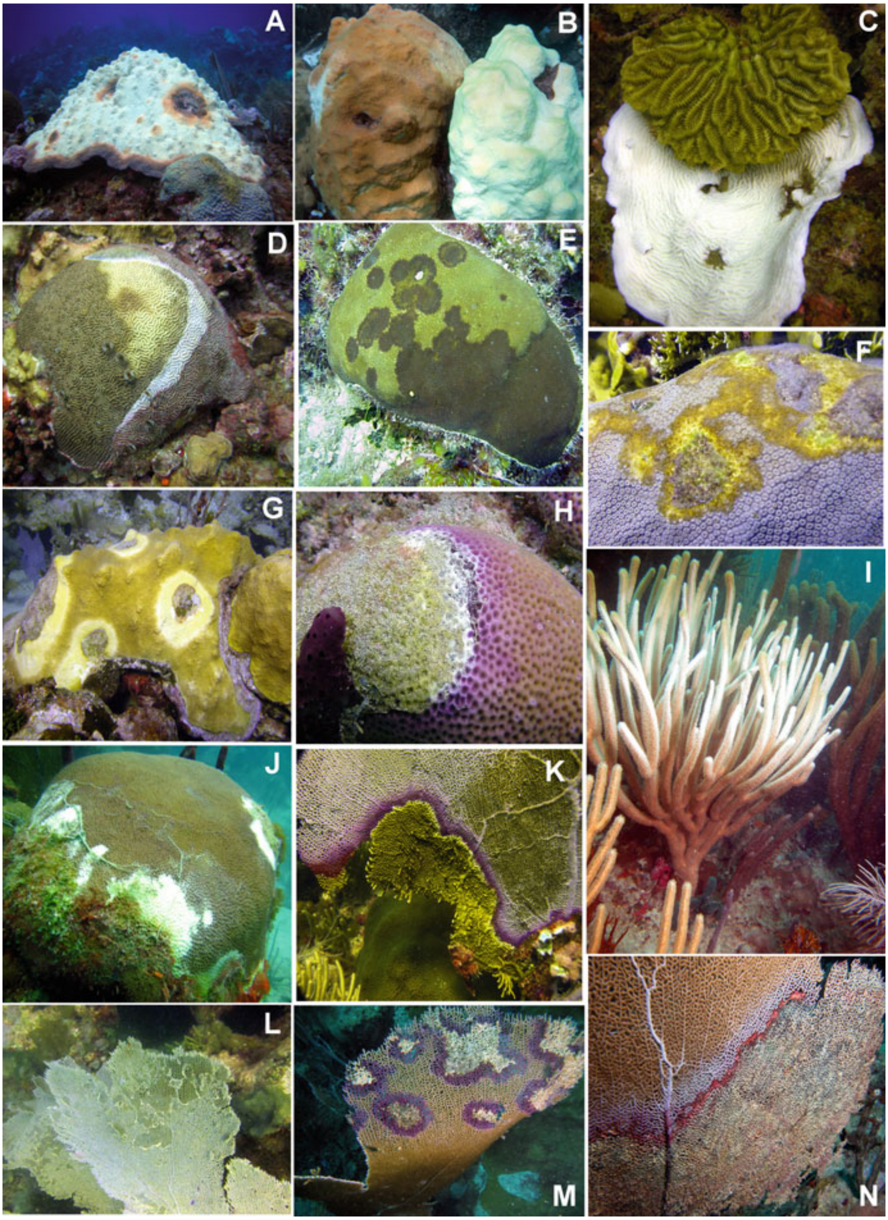

Fig. 6.4 Examples of stress and nociceptive ("pain") responses in Cnidarians. High temperatures induce the expulsion of zooxanthellae in corals and octocorals (i.e., bleaching) (**a–c, i**), with some colonies more susceptible than others (**b, c**); bacterial and fungal diseases produce immune responses that are visible at the edge of the advancing dying tissue as in white plague (**d, j**), dark spots (**e, f**), Caribbean yellow band (**g**), and black band disease (**h**). The sea fan *G. ventalina* first response is usually melanization (purple band) as in aspergillosis (**m**) and red band disease (**n**). Increased production of mucus is another protective response to noxious stimuli (**j, l**) (Photos E. Weil)

there are geographic and regional gaps and underrepresented areas that must be included in a global network of coral reef MPAs that enhances genetic connectivity. Such a network could provide the needed framework for the inclusion of welfare principles into the conservation/protection regulations for scleractinian corals and other important invertebrate groups on a local, regional, and global scale.

6.3 Cnidarian Conservation and Welfare in a Changing Sea

Observed trends of climate change and modeling predictions have shown that anthropogenic-driven (increasing CO_2 and other greenhouse concentrations) fast climate change will have unprecedented impacts on terrestrial and marine biodiversity in the near future with significant negative socioeconomic consequences across local and regional scales (Michener et al. 1997; Still et al. 1999; Mimura 1999; Stern 2006; Nicholls et al. 2008; Bonan 2008; Hoegh-Guldberg et al. 2007; Veron et al. 2009; Nicholls and Cazenave 2010; Bellard et al. 2012; Chindarkar 2012; Lane et al. 2013; NRC 2010; IPCC 2014; Scarponi et al. 2017). Human disturbances, inadvertent and intended, continue to threaten the survival of species and the maintenance of natural ecological and evolutionary processes worldwide (Parmesan 2006; Wilson 2006; Smith and Bernatchez 2008; Darimont et al. 2009; Jones et al. 2017). One of the most significant impacts of thermal anomalies associated with GCC is the alteration of organismal body temperatures, a stressful condition, which ultimately drives almost all physiological processes and responses, including growth and reproduction. Prolonged high and long thermal anomalies over weeks or months could cause corals to die from “heat stroke” (i.e., metabolic failure), starvation, infectious diseases, and/or other causes related to high temperature stress and low energy availability. The compromised-host hypothesis (sensu Rosenberg and Ben-Haim 2002) suggests that rising ocean temperatures may increase the number and prevalence (proportion of diseased individuals in a population) of diseases by making marine invertebrates more susceptible to ubiquitous pathogens or by causing shifts in resident microbial communities turning some of them pathogenic or more virulent. Increasing demands for colorful coral species and other coral reef invertebrates for the aquarium trade add more pressure on natural populations since captive coral cultures do not produce enough to satisfy the demand. This trade, as mentioned above, has no particular regulations on the welfare of the taxa involved during capture, transportation, and sales.

Coral reefs are one of the oldest ecosystems on Earth. Following the Permo-Triassic mass extinction event (251 MYA) and the evolution of the symbiosis with zooxanthellae, scleractinian corals have been the major builders of these impressive structures, the largest living structures on Earth (Goffredo and Dubinsky 2016; Hubbard et al. 2016; Rossi et al. 2017). Coral reefs have the highest biodiversity of all marine ecosystems and provide important ecological goods and services to other important tropical coastal communities, to the oceans in general, and to at least one billion humans around the world. Humans exploit these communities for food,

Table 6.3 Ecological/economic services provided by coral reefs

– Form 1/3 of the tropical coasts.
– Deposit up to 2000 ton/ha/year of $CaCO_3$ (carbon and calcium sink) and influence chemical balance of oceans.
• Absorb 1/2 of calcium entering oceans
• CO_2 sink (700 billion kg/year)
– Generate essential living habitat for important commercial species.
– Highest marine biodiversity and genetic reservoir.
– 20–35% of marine species depend on coral reefs.
– High primary productivity maintains a 9–15 million tons/year of fisheries.
– Direct source of proteins and income for >100 million humans and indirect services for probably over 1 billion.
– Source of active chemical compounds for medical/pharmaceutical applications.
– Supports a multibillion dollar tourism industry.
– Protect coastal communities from hurricanes and storms and replenish sandy beaches.
– Source of building material and limestone.
– Stabilize human social structures and provide areas for recreation and education.

Sources: Dubinsky and Stambler (2011), Bertness et al. (2014), Goffredo and Dubinsky (2016), Hubbard et al. (2016), and Rossi et al. (2017)

building materials, active pharmacological compounds, tourism, and other commercial products (Table 6.3). Unfortunately, their Cnidarian builders have been declining rapidly all over the world in the last 30–40 years. Disease emergence and disease outbreaks with extensive mortalities have exploded in marine communities in the last 30 years (Weil and Rogers 2011; Burge et al. 2014; Woodley et al. 2016). The highest and more widespread mortalities of Cnidarians and other important marine invertebrates in recent times in the Caribbean, Indo-Pacific, and Red Sea have been associated with high thermal anomalies linked to GCC and compounded by local/regional anthropogenic stressors such as pollution, coastal development, and overharvesting (Lessios et al. 1984; Hughes 1994; Hughes et al. 2004, 2010, 2017a,b, 2019; Aronson and Precht 2001; Gardner et al. 2003; Harvell et al. 2002, 2004, 2007, 2009; Bruno et al. 2003; Weil 2004; Ward and Lafferty 2004; Bellwood et al. 2004; Bruno and Selig 2007; Wilkinson and Souter 2008; Hoegh-Guldberg et al. 2007; Carpenter et al. 2008; McClanahan et al. 2009; Hoegh-Guldberg 2010; Dubinsky and Stambler 2011; Mumby and Van Woesik 2014; Jackson et al. 2014; Fuess et al. 2017; Lafferty et al. 2015; Lafferty and Hofmann 2016; Randal and van Woesik 2017; Weil et al. 2017 and references therein). Cnidarian populations and coral reefs are rapidly declining worldwide, mostly as a consequence of these mass mortalities with significant changes in the composition, structure, and function of these communities, and impacting the ecological services they provide.

High temperatures are also affecting the composition and structure of microbial communities associated with organisms and/or the environment, with unknown consequences. Geographic, latitudinal, altitudinal, and depth distributions of tropical terrestrial and marine pathogens, for example, are expected to increase in the near future as the planet warms up, with the potential of deadly outbreaks in susceptible species (Harvell et al. 2002, 2009; Stephens 2016; Weil et al. 2017). Intensive thermal anomalies have also affected foundation and keystone species all the way into temperate environments. Some recent examples include the thermally induced disease outbreaks that produced extensive mass mortalities of many species of sea stars along the northwest and northeast coasts of the United States (Fuess et al. 2017), oysters, lobsters, crabs, and other important economic invertebrate species (Burge et al. 2014; Groner et al. 2016).

The common denominator and most widespread problem of environmental deterioration is the uncontrolled growth of human populations, their industrial activities, and the exponential demands for natural resources and space, which have resulted in significant alteration of natural habitats, the overharvesting of many wildlife species, greater dependence on domesticated animals or cultured wildlife species, and changes in the functioning of most ecosystems. The current rate of environmental change is so fast that many indigenous wildlife populations cannot cope with the increasing demands and the synergistic impact of stressful conditions and are having trouble responding to their changing environments (Stockwell et al. 2003; Parmesan 2006; Hendry et al. 2008; Kolbert 2014; Jones et al. 2017). The consequence is an unprecedented environmental impact and a reduction in the effectiveness of affected habitats to support important species and biodiversity, with many species going extinct (Czech 2000). Common sense approaches to reduce these impacts such as habitat and species protection, sustainable use of resources, and welfare considerations for at least all the foundation and keystone species that build and support susceptible marine and terrestrial communities seem to scape the interest of leaders and policy makers.

Coral reefs are perhaps one of the most susceptible and impacted marine communities; therefore, there is an urgent need to protect the main cnidarians that build coral reef structures, as well as other important invertebrate species that build other essential marine communities or have important ecological functions, from the poles to the tropics and from shallow to abyssal habitats. The recent inclusion of the Caribbean acroporids coral species (*Acropora palmata* and *A. cervicornis*) in the ESA list is a good example of protection for two individual species. These foundation species are the fastest-growing taxa in the Caribbean and build three-dimensional structures that become essential fish habitats in short periods of time. They also provided refuge, habitat, and resources to thousands of other species, including commercially important ones. The IUCN list of threatened and endangered species includes 92 species of reef-building scleractinian species, but their level of protection varies significantly across countries. There are international conventions between nations dedicated to protecting endangered flora and fauna, but it is difficult to evaluate how efficient these are across the member countries. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is one example of these. Their goal is to ensure that international trade in specimens of wild animals and plants does not threaten their survival in their natural habitat, but does not include specific regulations on the welfare of the living organisms that are being traded, including capture, transport, and maintenance. Conservation/protection measurements usually include the creation of Marine Protected Areas (MPAs) with specific rules on the use and exploitation of the resources. These regulations should be complemented with welfare principles to increase conservation and survivorship of important taxa.

Human impacts and the general lack of concern for the protection of the very resources we need raise important questions about the ethical natural foundation of our contemporary society and the responsibility of what should we do to reduce/eliminate the environmental stress for our own future survival (Wilson 2006; United Nations Environment Programme 2007).

6.4 Final Remarks

Although most people and Federal Protection agencies show little concern or interest to the welfare of the majority of invertebrates, including Cnidarians, it is the increasing environmental deterioration and loss of taxa and ecological services provided to other important marine communities and to humans what is forcing some conservation actions to be established. Mounting evidence is suggesting that some, if not most, invertebrates could "feel" and "suffer" through current capture, transportation, research, or captivity practices that do not take into consideration their sensory capabilities to stress and "pain." These considerations should not stop with the manipulation of live specimens by humans, but should also be expanded to the natural populations that "suffer" when humans impact their environments and living conditions. Cnidarians, with their simple nerve networks, probably do not have cognitive responses to noxious and stressful stimuli, but their nociceptive responses should not disqualify them from considerations for welfare provisions. The fact that the animals show stress responses in general indicate some sort of "suffering" in their cnidarian "language," and this should be taken into consideration when ethical arguments are used to develop welfare provisions.

The increasing trade of marine organisms (coral reefs cnidarians and fish mostly) over the last decades is now considered a threat to the world's coral reefs (Rhyne et al. 2012; Jones et al. 2017). Obviously, there is an urgent need to implement welfare provisions to protect the species most commonly harvested or cultured for this trade. The question is how do we go about doing this. A potential approach to institute some welfare provision for cnidarians (and other keystone invertebrates) could be through the use of a combination of conservation arguments given their biological/ecological importance and the inclusion of ethical/humanitarian arguments given their capacity to "feel and suffer." In today's world of high tech, indoor entertainment and reduced contact with nature, it seems unlikely that humans will develop affinities for many invertebrate species. The access to technology and social media could (and should) be used to change this by spreading information and educate the public about the importance of and the high contributions that invertebrates make to natural communities and to humans in general (Schuldt et al. 2015). Hopefully this tactic could help improve the understanding and sympathy for most of the foundation, keystone and economically important species, and pressure government agencies to implement the needed welfare regulations.

Ocean health is deeply intertwined with the health and well-being of human societies because of all the valuable ecosystem services the important marine communities provide. Most of these communities are built or formed by invertebrates, which are key in carbon sequestration, heat absorption, and coastal erosion protection, and built essential fish and other invertebrate habitats, which are sources of animal protein for over a billion of the world's poorest that depend on healthy and well-functioning marine ecosystems such as coral reefs (Burge et al. 2014; IPCC 2014). Certainly we cannot expect welfare regulations for all Cnidarians or marine invertebrates immediately, but we can start protecting the foundation and keystone species and do so before the total crash and destruction of the important natural communities they help to construct and sustain.

Education is probably the most important tool that needs to be expanded globally to attract the much-needed public attention (Schuldt et al. 2015). The frequent news about bleaching and coral reef decline and how human activities and GCC are impacting these and other important communities around the globe is a good start. However, it seems that we need to continue to convince the general populations about the key problem, to reduce human population growth and, hence, the demand for more natural resources and space. This should help increase the support to combine conservation and welfare principles in the near future. Unfortunately, in today's social media and fast-news environment, these types of news and information are downplayed and avoided or, if listened, are quickly forgotten. The process should start at an early age and continue throughout the whole educational curriculum because it seems obvious that the majority of policy makers and today's politicians are more driven by economic gains than the protection of our future. Education and continuous advertising and news over the social media communication networks may make a difference. The more exposure to the current problems and future forecast to the general public, the higher the chance they will understand the problems and change their attitudes. The current and increasing threats to the world's biodiversity, ecosystems, and natural resources, with cnidarians and other important foundation groups at risk in the near future, underscore the need to act fast and develop comprehensive sustainable conservation/protection measures that include both ecological and ethical (welfare) principles.

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