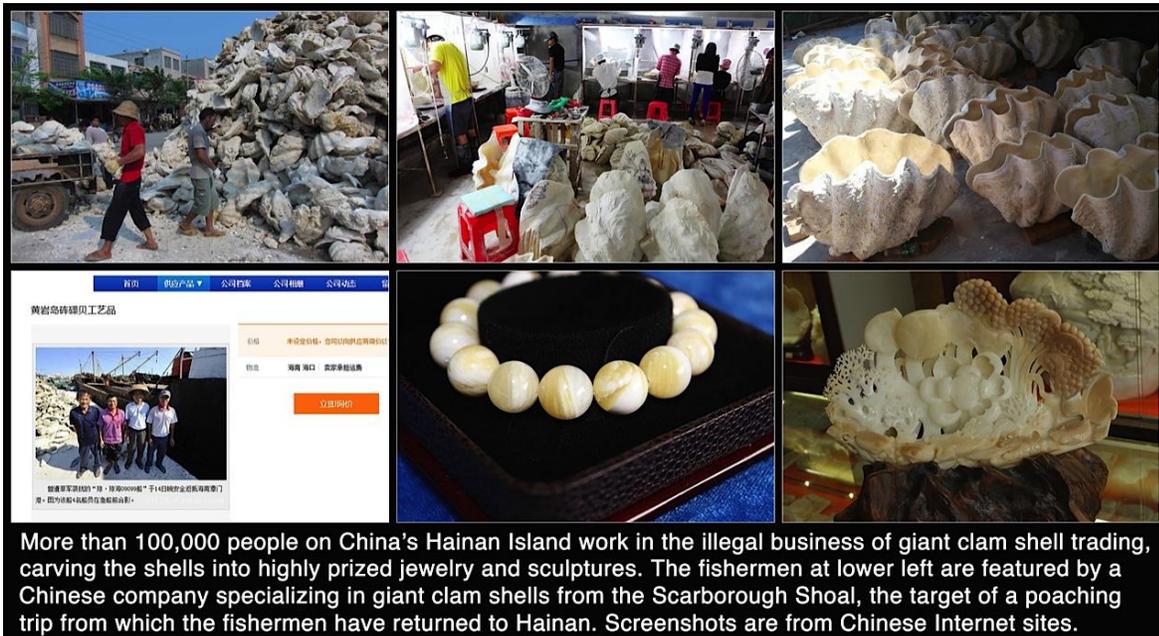


# PETITION TO LIST THE TRIDACNINAE GIANT CLAMS (excluding *Tridacna rosewateri*) AS THREATENED OR ENDANGERED UNDER THE ENDANGERED SPECIES ACT

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Non-official communication of interest

## NOTICE OF PETITION

7 August 2016

Donna Wieting, Director  
Office of Protected  
Resources, F/PROD  
National Marine Fisheries  
Service 1315 East West  
Highway  
Silver Spring, MD 20910  
[donna.wieting@noaa.gov](mailto:donna.wieting@noaa.gov)

Dear Ms. Wieting,

Pursuant to section 4(b) of the Endangered Species Act (“ESA”), 16 U.S.C. § 1533(b), section 553(3) of the Administrative Procedure Act, 5 U.S.C. § 553(e), and 50 CFR 424.14(a), Dwayne W. Meadows, Ph.D. hereby petitions the Secretary of Commerce, through the National Marine Fisheries Service (“NMFS”, the lead office for implementing the ESA), to list the Tridacninae Giant Clams (excluding *Tridacna rosewateri*) as a threatened or endangered species under the ESA (16 U.S.C. §§ 1531 *et seq.*) throughout all or a significant portion of their ranges. *Tridacna rosewateri* occurs only in Mauritius and there is no additional information on the status of this species, so it is not considered further as part of this petition.

NMFS has jurisdiction over this petition because the petitioned species are marine. This petition sets in motion a specific process, placing definite response requirements on NMFS. Specifically, NMFS must issue an initial finding as to whether this petition “presents substantial scientific or commercial information indicating that the petitioned action may be warranted.” 16 U.S.C. § 1533(b)(3)(A). NMFS must make this initial finding “[t]o the maximum extent practicable, within 90 days after receiving the petition.” *Id.* The petitioner does not need to demonstrate that listing of the Tridacninae is warranted, rather, petitioner must only present information demonstrating that such listing may be warranted. While petitioner believes that the best available science demonstrates that listing of the Tridacninae is in fact warranted, there can be no reasonable dispute that the available information indicates that listing the species may be warranted. As such, NMFS must promptly make a positive initial finding on the petition and commence and complete a status review as required by 16 U.S.C. § 1533(b)(3)(B). Petitioner also requests that critical habitat be designated for the Tridacninae that occur in U.S. waters concurrently with the species being listed as endangered or threatened, pursuant to 16 U.S.C. § 1533(a)(3)(A) and 50 C.F.R. § 424.12.

## INTRODUCTION

This petition summarizes the natural history of the Tridacninae species, the population information available on the species, and the threats to these giant clams and their habitat. The petition then shows that, in the context of the ESA's five statutory listing factors, the Tridacninae warrant listing as endangered or threatened under the Act due to loss or curtailment of habitat or range, overutilization, the inadequacy of existing regulatory mechanisms to safeguard the species, and other factors including global climate change and inherent vulnerability to population decline and slow recovery and low resilience. Lastly, the petitioner requests that critical habitat be designated for the Tridacninae in U.S. waters concurrently with listing.

Recent media stories report on discoveries of massive fishing efforts and habitat destruction by Chinese fisherman (BBC 2015, Grind TV 2015, Bale 2016, Diplomat 2016, Larson 2016). A main target is the giant clam (*Tridacna gigas*). The shells of this species are considered a desirable luxury item and are thought to confer supernatural powers and improve health in China (Diplomat 2016). A pair of high quality shells selling for \$150,000 (Diplomat 2016). Evidence shows that the fishing has occurred in the presence of both the Chinese Navy and Coast Guard (Diplomat 2016), showing that any potential domestic Chinese regulations that exist are not enforced in point of fact. Further, the Chinese website Alibaba has 2 dozen pages devoted to giant clam products for sale. In 2012 the Chinese government encouraged the development of Tanmen's fishery for giant clams. The efforts are closely involved in China's efforts to construct military and commercial outposts in the disputed islands of the South China Sea. The industry supports 100,000 people in Tanmen alone (Cavell 2016). The number of boats fishing for giant clams has grown in Tanmen from 3-4 to dozens in the past 5 years, each capable of collecting hundreds of shells a day (Cavell 2016). Bale (2016) reports that satellite imagery analysis shows over 40 square miles of giant clam habitat on coral reefs in the South China Sea have been destroyed by giant clam poaching. Another 22 square miles have been destroyed by island-building activities, mostly by the Chinese government.

Vietnamese and Filipino fishermen have also been arrested for giant clam poaching (Diplomat 2016), so the problem is widespread in the western Pacific and areas where fishermen from those countries fish.

The giant clams have not been evaluated by the IUCN since 1996, when their status was already dire. Much newer information suggests their populations have declined significantly range-wide and threats have increased (see below).

Giant clams are also known to play ecologically important roles in community structure on reefs. Giant clams have among the highest net primary productivity rates of any primary producers on coral reefs, including most corals and algae (Neo et al. 2015). They provide a surface for many epibionts, creating new communities dependent on them and thus serving as keystone species (Hardy and Hardy 1969, Mingoa-Licuanan and Gomez 2002, Mekawy 2013, Neo et al. 2015); commensal and ectoparasitic organisms live within the habitat of their mantle cavities (Neo et al. 2015); and they are food for a variety of predators and scavengers (Neo et al. 2015). Giant clams also potentially counteract eutrophication via water filtration and are an anchor for the coral reef matrix itself (Neo et al. 2015).

## TAXONOMY

Giant clams are in the order Veneroida and family Cardiidae of the bivalve molluscs. There are 2 genera: *Tridacna* with nine species and *Hippopus* with two (bin Othman et al. 2010). The nine *Tridacna* species are: *costata*, *crocea*, *derasa*, *gigas*, *maxima*, *noae*, *rosewateri*, *squamosa*, and *tevoroa* (also known as *mbalavauna*); the two *Hippopus* are: *hippopus* and *porcellanus*. Huelskin et al. (2013) and Mohamed et al. (2006) use genetic data to suggest there are additional widespread cryptic species that are unnamed.

Giant clams used to be considered their own family Tridacnidae, and that is how they are still listed in CITES. Genetic data and a study of sperm ultrastructure some years ago however made the giant clams a subfamily (Tridacninae) of the cardiids (Schneider and O’Foighill 1999, Keys and Healy 2000, Schneider 2002), and the CITES taxonomy is generally considered invalid. Herrera (2013) confirmed the monophyly of Tridacninae.

A few species are very similar. *Tridacna rosewateri* (Sirenko and Scarlato 1991) occurs only in Mauritius (Wells 1996c) and is closely related to *T. squamosa* (Newman and Gomez 2000). *Tridacna rosewateri* differs from *T. squamosa* in having 1) a thinner shell, 2) larger byssal orifice, 3) scales more densely arranged on the primary ribs, and 4) larger interdigitating occludent projections (Newman and Gomez 2000). *Tridacna noae* has had a tumultuous history, being considered an invalid species at times, but the current research suggests it is a valid species (Su et al. 2014, Borsa et al. 2015a). They are easily confused with *T. maxima* and shell morphology is not discrete between these species (Borsa et al. 2015b). However, *Tridacna noae* sympatric with *T. maxima* were larger (206 vs 161 mm)(Militz et al. 2015). Live Noah’s giant clams are better diagnosed by the discontinuous disposition of the hyaline organs, and by the large, easily recognizable, ocellate spots with a thin, white contour on the mantle’s edge (Su et al. 2014). MtDNA phylogenies identify *T. noae* as a distinct clade, separated from *T. maxima* by 17–26 % nucleotide divergence at the cytochrome-oxidase 1 locus and 4–5 % nucleotide divergence at the ribosomal RNA subunit 16S locus (Su et al. 2014).

Major sub-genera groupings within *Tridacna* are: Chametrachea (comprising *T. squamosa*, *T. crocea* and *T. maxima*), *Tridacna sensu stricto* (containing only *T. gigas*), and Persikima (comprising *T. derasa* and *T. tevoroa*)(Benzie and Williams 1998). Persikima is intermediate between Chametrachea and *T. gigas* (Benzie and Williams 1998).

## NATURAL HISTORY

Giant clams have evolved an obligate symbiosis with photosynthetic dinoflagellate algae of the genus *Symbiodinium*, which live in their enlarged siphonal mantle (Schneider 1988, Baillie et al. 2000). These are the same type of dinoflagellates that live symbiotically with reef-building corals. As a result these clams also tend to live in shallow and clear waters (bin Othman et al. 2010). Thus many of the same issues and threats affecting corals are likely to affect giant clams, including bleaching and the effects of climate change and global warming. See Brainard et al. (2011), 77 FR 73219, and 79 FR53852 for full discussion of these threats, to be incorporated by reference herein.

Giant clams have relatively late sexual maturity, a sessile, exposed adult phase and broadcast spawning strategy, all of which make them vulnerable to depletion and exploitation (Neo et al.

2015).

Giant clams are also known to play ecologically important roles in community structure on reefs. Giant clams have among the highest net primary productivity rates of any primary producers on coral reefs, including most corals and algae (Neo et al. 2015 (Figure 1)). They provide a surface for many epibionts creating new communities (Hardy and Hardy 1969, Mingoa-Licuanan and Gomez 2002, Neo et al. 2015); commensal and ectoparasitic organisms live within their mantle cavities (Neo et al. 2015); and they are food for a variety of predators and scavengers (Neo et al. 2015). They potentially counteract eutrophication via water filtration and are an anchor for coral reef matrix (Neo et al. 2015).

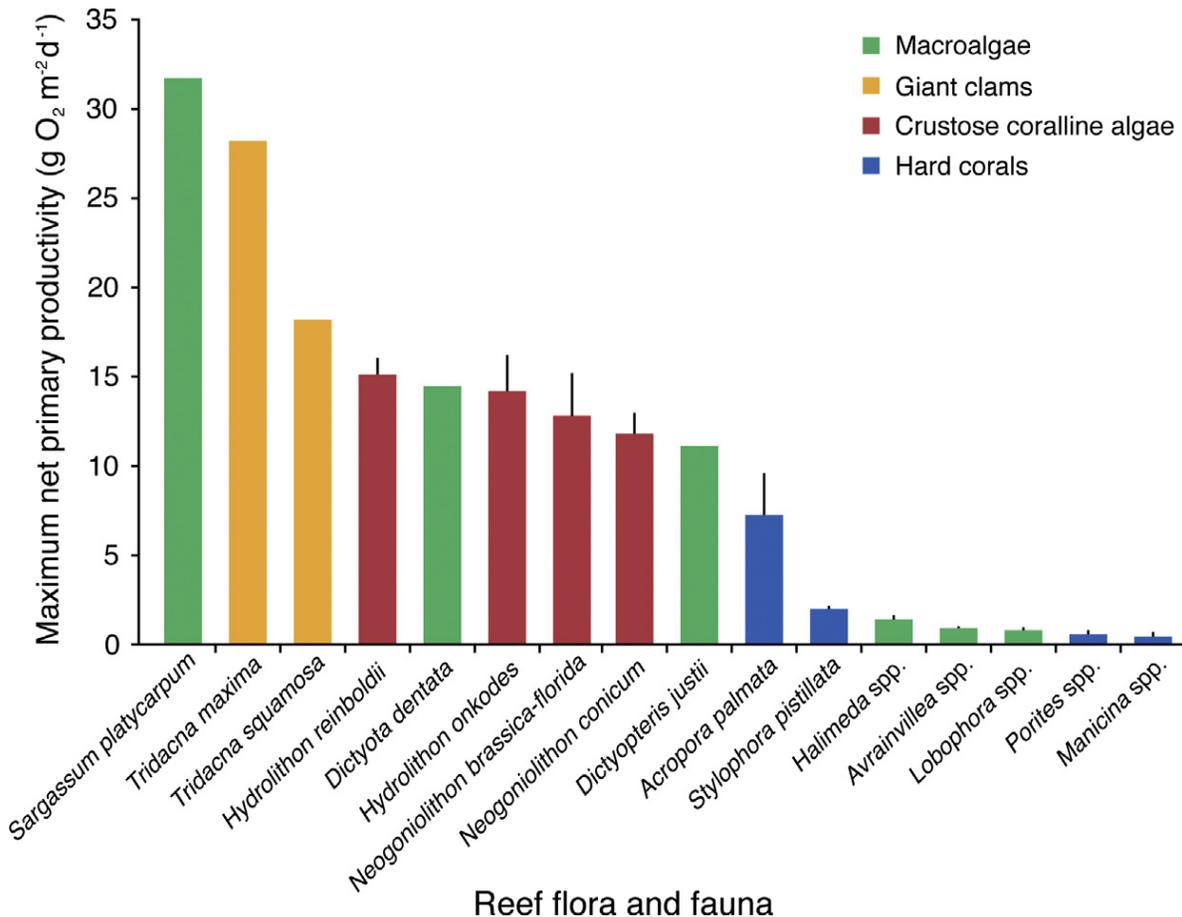


Fig. 1. Maximum net primary productivity (NPP) of different reef flora and fauna, measured in terms of net oxygen production (units = g O<sub>2</sub>/m<sup>2</sup>/d). NPP values are arranged from the highest to lowest producers. Standard deviation provided when available. Information extracted from: Wanders (1976), Rogers and Salesky (1981), Porter et al. (1984), Chisholm (2003), Jantzen et al. (2008), Naumann et al. (2013). (from Neo et al. 2015).

## DESCRIPTION

*Tridacna gigas* is the largest species, reaching 120 cm and 200 kg (Neo et al. 2015). *Deresa* is the second largest species, growing up to 60 cm (Neo et al. 2015). *Porcellanus* reaches 40cm, while *T. crocea* is the smallest species, reaching only 15cm. *Tridacna crocea* is also unusual in

that it burrows rather than being attached like the other giant clams (Neo et al. 2015). *Tridacna maxima* has close-set scutes and grows up to 35 cm; it tends to bore partially into reef substrates (Neo et al. 2015).

*Tridacna tevoroa* is most like *T. derasa* in appearance, but is distinguished by its rugose mantle, prominent guard tentacles present on the incurrent siphon, thinner valves, and colored patches on shell ribbing. It can grow to just over 50 cm long (Neo et al. 2015). *Tridacna rosewateri* reaches 19 cm as does *T. squamosa* (Neo et al. 2015). *Tridacna costata* grows to 32cm (Neo et al 2015).

## **RANGE**

Extant giant clams only exist in the Indo-Pacific region. However, there are 15 recognized fossil species and the origin of the group is Tethyan in the Paleogene with the Atlantic species going extinct (Newman and Gomez 2000). Four of the extant species have restricted ranges while the others are quite widespread throughout the Indo-Pacific (Figure 2). *Hippopus porcellanus* occurs only in Indonesia, Palau and the Philippines (Wells 1996b). *Tridacna costata* only occurs in the Red Sea (bin Othman 2010). *Tridacna rosewateri* occurs only in Mauritius (Wells 1996c). There is no additional information on the status of this species so it is not considered further as part of this petition. *Tridacna tevoroa* is restricted to Fiji and Tonga (Neo et al 2015).

Of the more widespread species, *Tridacna noae* (Figure 2) is known from Taiwan, Japan, Dongsha (northern South China Sea), Bunaken (Sulawesi Sea), Madang and Kavieng (Bismarck Sea), the Alor archipelago (Sawu Sea), Kosrae (Caroline Islands), New Caledonia, the Loyalty Islands and Vanuatu (Coral Sea), Viti-Levu (Fiji), Wallis Island, and Kiritimati (Northern Line Islands). (Borsa et al. 2015b). Published mtDNA data also indicate its presence in eastern Negros (Philippines), in the Molucca Sea, at Ningaloo Reef (Western Australia), and in the Solomon Islands (Borsa et al. 2015b).

Gilbert et al. (2007) recorded the first observations and a range extension for *T. squamosa* into French Polynesia.

Neo and Todd (2012b, 2013) report there are five giant clam species that historically occurred in Singapore (*H. hippopus*, *T. crocea*, *T. gigas*, *T. maxima*, and *T. squamosa*). The IUCN (Wells 1996d) failed to correctly note the range of *T. gigas* included Singapore.

The United States and its territories and possessions are in the range of (or historically contained) at least *H. hippopus*, *T. derasa*, *T. gigas*; *T. maxima*, and *T. squamosa*.

## **HABITAT**

Giant clams typically inhabit coral reefs but this is not an obligate relationship (Munro 1992) as the key for most is suitable substrate and environmental conditions. Water temperature should range from 25-30°C (Ellis 1997).

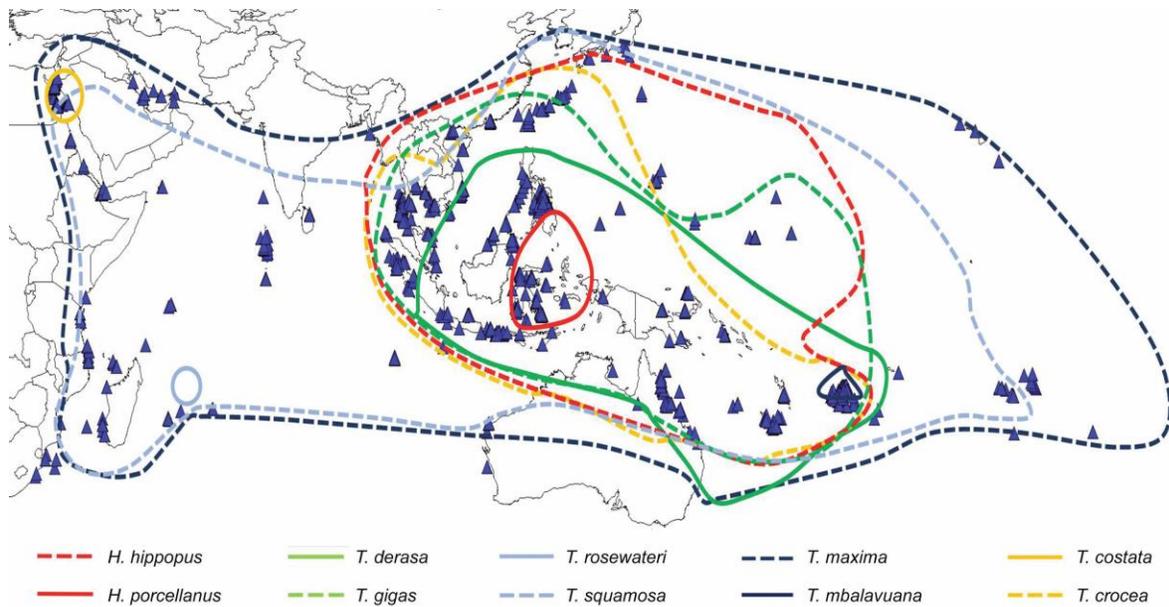


Fig. 2. Distribution of giant clams. Adapted from Rosewater (1965, 1982); Lucas (1988); Howard (1988); Zann & Ayling (1988); Gomez & Mingo-Licuanan (2002) and Richter et al. (2008). The blue triangles represent Reef Check records and therefore the species are unknown. Abbreviation used for genera: T., *Tridacna*; H., *Hippopus*. Does not include *T. noae*. (from bin Othman et al. 2010).

Hamner and Jones (1976) found that *T. crocea* settle preferentially on the top of detached coral heads in the reef flat of the Great Barrier Reef. The species burrows as it grows, eroding the central top surfaces of coral boulders, resulting in structures that superficially resemble micro-atolls. The species also appears to aggregate, though the mechanism is unclear, aggregation may enhance physical stabilization, facilitate reproduction, or provide protection from predators (Soo and Todd 2014).

*Tridacna derasa* preferentially inhabits clear offshore or oceanic waters away from high islands with significant run-off of freshwater (Munro 1992). For example, it is not recorded from the Papuan Barrier Reef running along the south coast of Papua New Guinea (PNG), nor from the fringing reefs of the north coast of PNG but makes its appearance within a few miles of the south-east point of mainland PNG (Munro 1992). Large *T. derasa* were also commonly found at 10 to 20 m depth in the clear oceanic conditions of the windward islands and barrier reefs of eastern Fiji (Adams et al. 1988).

*Tridacna gigas* is found in many habitats, whether high- or low-islands, lagoon or fringing reefs, and in this respect is matched by *H. hippopus* which has a similar geographical distribution and even a wider range of habitats (Munro 1992).

*Tridacna maxima* has been shown to respond to conspecifics and habitat cues for settlement.

*Tridacna squamosa* favors fairly sheltered lagoon environments adjacent to high islands but in the closed atoll lagoons of Polynesia appears to be excluded by *T. maxima* (Munro 1992). Neo et al. (2009) found that *T. squamosa* larvae, like many reef invertebrates, prefer substrate with crustose coralline algae.

*Tridacna tevoroa* live along outer slopes of leeward reefs in Fiji, in very clear, oceanic water at 9-33 m (Ledua et al. 1993).

## LIFE HISTORY

All giant clams are protandrous hermaphrodites, becoming simultaneous hermaphrodites in later years (Munro 1992). They mature as males in 2-3 years (Ellis 1997). In the central tropics there is no evidence of any seasonality in reproduction (Munro and Gwyther 1981, Beckvar 1981, Heslinga et al. 1984, Soo and Todd 2014) but it appears that gonads ripen on a seasonal basis at the northern and southern limits of distribution because spawning of *T. gigas*, *T. crocea* and *H. hippopus* is restricted to a short summer season in the central region of the Great Barrier Reef (Munro 1992). On Palau, *Hippopus hippopus* spawned in June and *Tridacna crocea*, in July (Hardy and Hardy 1969). Stephenson (1934) and Shelley (1989) reported that *H. hippopus* spawns in the austral summer months of December to March on the Great Barrier Reef. Using the hypodermic extraction technique, Braley (1988) found that the optimal reproductive season for *T. gigas* was Oct.-Feb., and in *T. derasa* from September/October to November/December *Tridacna maxima* spawned during the winter months in Guam and Fiji (LaBarbera 1975). Spawning in giant clams has been shown to follow both a diel and lunar pattern (Heslinga et al. 1990, Braley 1992a, Soo and Todd 2014). Spawning activity tends to be highest in the mid to late afternoon and during full and new moon periods (Ellis 1997). However, Braley (1984) found diel periodicity to the spawning of *T. gigas* generally coincided with incoming tides near second (full), third and fourth (new) quarters of the moon phase.

Jameson (1976) estimated fecundity (F) of *T. maxima* as  $F = 0.00743$ , so a ripe gonad of a 20 cm specimen would therefore contain about 20 million eggs. Individual *T. gigas* in the 70-80 cm size range have produced up to 240 million eggs (Munro 1992).

Giant clams are of course broadcast spawners. So, unfortunately, it is a feature of giant clam biology that stocks will become non-sustaining when densities fall below certain thresholds (Lucas 1988). Sperm release precedes egg release during spawning, presumably to prevent self-fertilization (Ellis 1997). Giant clam eggs contain, or are associated with, a chemical which induces spawning in a conspecific clam which detects the spawning inducer (Munro 1992). Sperm is released by the second clam and the eggs are thus fertilized. The second clam might also release eggs after an interval and the entire process progresses downstream. However, if there is no conspecific clam downstream the eggs are unfertilized and the chain of events does not eventuate or continue (Munro 1992). In other words there is a minimum density, below which there is likely to be little spawning, even if adults persist. In other words there is an Allee effect. Thus total abundance is not a good indicator of species status. In fact, Braley (1987) found that 70% of the *T. gigas* neighbors that released gametes naturally were within 9 meters of each other.

Early larval development of giant clams is typical of bivalves; lecithotrophic eggs are approximately 100  $\mu$ m in diameter and hatch into ciliated free-swimming trochophores within 12 hours of fertilization (Ellis 1997). In a detailed study of early life history in Guam, fertilized eggs of *T. crocea*, *T. maxima*, and *H. hippopus* had mean diameters of 93.1, 104.5, and 130.0  $\mu$ m, respectively (Jameson 1976).

The trochophore develops into a filter feeding, planktotrophic bivalve veliger or D-stage larva of

160 mm shell length approximately two days after fertilization (Ellis 1997, Soo and Todd 2014). The day-2 straight-hinge veligers of *T. crocea*, *T. maxima*, and *H. hippopus* had mean shell lengths of 155.0, 168.0, and 174.4  $\mu\text{m}$ , respectively (Jameson 1976).

The veliger later develops a foot to become a pediveliger (Figure 10) that alternately swims and rests on the substrate, eventually metamorphosing into a 200 mm juvenile clam at day 8-10 post-fertilization (Ellis 1997). Metamorphosis is physically characterized by a sloughing off of the velar tissues and cilia and marks the beginning of the symbiotic relationship with the zooxanthellae (Ellis 1997). Settlement in Guam occurred 12, 11, and 9 days after fertilization at a mean shell length of 168.0, 195.0, and 202.0  $\mu\text{m}$  for *T. crocea*, *T. maxima*, and *H. hippopus*, respectively (Jameson 1976). Metamorphosis was basically complete about 1 day after settlement. Juveniles of *T. crocea*, *T. maxima*, and *H. hippopus* first acquire zooxanthellae after 19, 21, and 25 days, respectively. Growth rates increase sharply after the acquisition of zooxanthellae. Juvenile shells show first signs of becoming opaque after 47 days for *T. maxima* and after 50 days for *H. hippopus* (Jameson 1976). Thus dispersal is likely limited and divergence and population structuring is a potential issue.

Zooxanthellae are acquired early in life by into the stomach via the mouth and come from external sources; zooxanthella were not seen in either the fertilized eggs or trochophore stages (Fitt and Trench 1981, Fitt et al. 1986). Within several days after metamorphosis from veliger to a juvenile clam, the zooxanthellae tube, in which zooxanthellae were packed, elongated from the stomach toward the mantle where the zooxanthellae will reside permanently (Hirose et al. 2006). Fitt and Trench (1981) had similar but less extensive observation of *T. squamosa*. Survival and growth of veligers and juveniles with zooxanthellae was greater than those without zooxanthellae (Fitt and Trench 1981, Fitt et al. 1986). The newly acquired zooxanthellae bring photosynthetically-fixed carbon into the new symbiosis and was responsible for the increased veliger growth and survival (Fitt et al. 1986). Fitt et al. (1986) found that symbiotic dinoflagellates contribute significantly to growth and development, even of larval and juvenile giant clams.

Growth generally follows a sigmoid curve, starting off slowly then accelerating after approximately 1 year and slowing again as the animals approach maturity (Ellis 1997). Pearson and Munro (1991) established growth curves of *T. derasa* and *T. gigas* on the GBR and found annual mortality of 4.4% and 3.4-10.7%, respectively. *T. gigas* has the highest growth rate of all the species (Blidberg et al. 2002). Smith (2011) found growth of *T. maxima* was similar at northern and southern Great Barrier Reef sites. Jones et al. (1986) used stable isotope analysis and shell-banding growth studies of *Tridacna maxima* to reveal the existence of two growth phases related to sexual maturity that can be discerned in the shells of both extinct and extant individuals. The change from the first to second reproduction-oriented phase occurs at an age of approximately 10 years and is accompanied by a decrease in rate of calcification.

Size and age at maturity varies with species and geographical location (Ellis 1997). Shelley (1989) found second sex maturity in *H. hippopus* at 145 mm with presumed male maturity at 2 years and hermaphrodite at 4 years. *Tridacna maxima* begin to reach sexual maturity as males in the Cook Islands at approximately 6 cm; 50% of both males and females were sexually mature at 10 cm; and 100% were sexually mature at 14 cm and larger. The species was also very slow growing there and took five years to reach 10 cm in length, 10 years to reach 15 cm and 15 to 20 years to reach 20 cm and above. Only 21.5% of the population were fully sexually mature, indicating likely overfishing.

Han et al. (2008) found that the scutes on *T. squamosa* shells serve as adaptations against crushing predators like crabs. Neo et al. (2011) extended this work to show that water-borne cues from a predatory crab induced changes in shell morphology to strengthen shell defenses.

There are major differences between typical non-symbiotic bivalves and *Tridacna gigas* regarding the relative allocations of energy to respiration and growth. The proportion of carbon deposited in tissues relative to that respired is high in giant clams relative to completely heterotrophic bivalves. The spectacular rates of growth in this clam are such that filter feeding is able to provide 65% of the total carbon needed both for respiration and growth in small clams (100 mg dry tissue wt), whereas large clams (10 g) acquire only 34% of their carbon from this source. In other giant clam species symbionts provide an increasing percentage of carbon and nitrogen respiratory requirements as the clams grow (see references in Yih Yau and Tung-Yung (2012)).

## ECOLOGY

Sunlight is important for photosynthesis to occur in the symbiotic zooxanthellae, and only one species of giant clam, *T. tevoroa*, occurs at depths below 20 m. The species do differ in their range of phototrophy. Mild siltation or turbidity can be tolerated by some giant clam species, but clear, tropical, oceanic water is preferable. Klumpp and Lucas (1994) compared nutrition of *T. tevoroa* with *T. derasa* in Tonga to better understand how *T. tevoroa* survives in deeper waters. Rates of filter-feeding, respiration and the photosynthesis-irradiance response were measured in clams of a wide size range (ca 20 mm to ca 500 mm) which had been acclimated to 4 levels of shading, simulating depths of 1, 5, 15 and 28 m. Rates of respiration, growth, filter-feeding and maximum photosynthesis did not vary between species or level of shading. Only *T. tevoroa* significantly increased its photosynthetic efficiency with increasing depth. At their normal depths, phototrophy provides most (70% at 28 m, 105% at 15 m) of the carbon required for growth plus maintenance, and filter-feeding is a relatively minor source (8 to 14 %).

Ishikura et al. (1999) studied *T. crocea* and found the main product of the zooxanthellae provided to the clam was glucose, as is the case for *T. gigas*.

Klumpp et al. (1992) showed that *T. gigas* is an efficient filter-feeder and that carbon derived from filter-feeding in Great Barrier Reef waters supplies substantial proportions of the total carbon needed for respiration and growth. This proportion is size-dependent, decreasing from 65% in 42.5 mm shell length clams to 34 % at 167 mm shell length. Klumpp et al. (1992) found that *T. gigas* retained 75% of particles between 2 and 50  $\mu\text{m}$ , and absorbing from them 54% of carbon. Leggatt et al. (2000) showed that the zooxanthellae in *T. gigas* giant clams use  $\text{CO}_2$  as the primary source of their carbon in contrast to similar symbionts in corals, which use bicarbonate.

Findings by Jantzen et al. (2008) suggest *T. maxima* is a strict functional photoautotroph limited by light, whereas *T. squamosa* is a mixotroph whose photoautotrophic range is extended by heterotrophy.

*Turbonilla* sp. is a small pyramidellid gastropod that is an ectoparasite on the giant clam, *Tridacna gigas*. In field surveys of an intertidal culture site at Orpheus Island, Great Barrier

Reef, 9–17% of the juvenile clams were found to be infested with *Turbonilla sp.*, and this occurred in an aggregated pattern (Boglio and Lucas 1997). Growth experiments showed that the parasites were lethal in cases of heavy infestations on juvenile clams and that they reduced clam growth in sublethal infestations. Reduction in growth rate was related to clam size and number of parasites. The estimated total losses of linear growth rate and productivity of infected clams were 2.8–4.2% and about 7%, respectively.

Soo and Todd (2014) review behavior in tridacninaes as they believe this component of their autecology is critical to their life history and hence conservation. Perhaps surprisingly, giant clams have considerable mobility, ranging from swimming and gliding as larvae to crawling in juveniles and adults. Soo and Todd (2014) review behavior in tridacninaes as they believe this component of their autecology is critical to their life history and hence conservation. Because of their shell weight and/or byssal attachment, adult giant clams are unable to escape rapidly from threats using locomotion. Instead, they exhibit a suite of visually mediated anti-predation behaviors that include sudden contraction of the mantle, valve adduction, and squirting of water. Chemotaxis and geotaxis have been established, but giant clams are not phototactic (Soo and Todd 2014).

Giant clams are also known to play ecologically important roles in community structure on reefs. They have among the highest net primary productivity rates of any primary producers on coral reefs, including most corals and algae (Neo et al. 2015). They provide a surface for many epibionts, creating new communities dependent on them and thus serving as keystone species (Hardy and Hardy 1969, Mingoa-Licuanan and Gomez 2002, Mekawy 2013, Neo et al. 2015); commensal and ectoparasitic organisms live within the habitat of their mantle cavities (Neo et al. 2015); and they are food for a variety of predators and scavengers (Neo et al. 2015). Giant clams also potentially counteract eutrophication via water filtration and are an anchor for the coral reef matrix itself (Neo et al. 2015).

## POPULATION STRUCTURE

Many of the species of giant clams show evidence of population structure and subdivision. While Distinct Population Segments of invertebrates cannot be designated under the ESA, evidence of population structuring is relevant to the status of species, with more subdivided species at greater risk of extinction.

Junio-Menez et al. (2003) found genetic structure in 13 populations of *T. crocea* around Palawan (western Philippines and South China Sea). Ravago-Gotanco et al. (2007) sampled 15 populations of *T. crocea* from the eastern Philippines in order to examine the influence of the North Equatorial Current (NEC) bifurcation on population genetic structure. They found significant genetic differentiation among all populations with two regional groups and a north–south spatial genetic structure broadly concordant with the bifurcation of the NEC. *Tridacna crocea* also shows a very strong genetic population structure and isolation by distance, indicating restricted gene flow between almost all sample sites, in the Indo-Malay archipelago in a study by Kochzius and Nuryanto (2008). At a slightly wider scale, DeBoer et al. (2014) used mtDNA and microsatellites from 27 populations of *T. crocea* across Indonesia and the Philippines to identify three genetically distinct regions: (1) Western Indonesia, (2) Philippines and Central Indonesia, and (3) Eastern Indonesia. Thus *T. crocea* is the best studied species and has population

structuring at all level studied.

Macaranas et al. (1992) found large genetic differences among populations of *T. derasa* from Australia, Fiji, and the Philippines. This is in contrast with low genetic divergence of *T. gigas* over similar range (Benzie and Williams 1992a, b).

Benzie and Williams (1995) however did find population substructuring in *T. gigas* over an even wider area, with separate Central Pacific and Western Pacific subpopulations evident in their data. Gene flow among the 13 sample populations in the Pacific did not follow ocean circulation patterns. The authors suggest that the genetic structure of *T. gigas* reflects historical patterns of migration when sea levels were lower than they are now, rather than present day dispersal. Evans and Jerry (2006) found low levels of genetic structure among 4 north-central GBR populations of *T. gigas* but suggested there may be differences between north and south Great Barrier Reef that would warrant care with translocation and management.

Kittiwattanawong (1997) found high genetic diversity of *T. maxima* at three sites in Thailand with evidence of two subpopulations in the Andaman Sea. Extensive surveys of genetic variation at eight polymorphic loci in 19 populations of *T. maxima* sampled throughout the West and Central Pacific, also by Benzie and Williams (1997), confirmed that the patterns of variation seen so far in *T. gigas* across the Pacific were not unique to that species. Also for *T. maxima*, Campbell et al. (1975) found high genetic variability from Heron Island on the Great Barrier Reef, confirming that the high variability found in a prior study at Enewetak Atoll was not related to exposure to nuclear tests there. Benzie and Williams (1992b) found genetic structure varied with distance in *T. maxima* from the Western Coral Sea with no other discrete structuring in that area. Tisera et al. (2013) found high genetic variation among five *T. maxima* populations around the Savu Sea, of Indonesia which they later confirmed with additional data from the CO1 mtDNA gene (Tisera et al. 2013). Laurent et al. (2002) found genetic evidence for selection in *T. maxima* among archipelagos in French Polynesia which suggests adaptive evolutionary differences and population structure in the region.

Kittiwattanawong et al. (2001) found high genetic divergence between *T. squamosa* from the Andaman Sea and Gulf of Thailand.

Hui (2012) and Hui et al. (2016) studied the population genetic structures of three giant clams (*Tridacna crocea*, *T. maxima* and *T. squamosa*) in Indo-West Pacific and found significant regional barriers to gene flow and six “ESUs”: Western Indian Ocean, Red Sea, Eastern Indian Ocean, central Indo-Malay Archipelago, Western Pacific and Central Pacific. Hui’s work is concordant with all of the previously discussed work on population structure in these three species.

In sum, population substructuring has been reported at both small and large spatial scales in all species of giant clams studied.

## **ABUNDANCE and POPULATION TRENDS**

Populations of wild giant clams are declining or have declined severely across the globe for all species (Pringgenies et al. 1995, Teitelbaum and Friedman 2008), even to the point of local and regional extirpation.

Richter et al. (2008) show that *T. costata* used to make up 80% of the giant clams in its range but now represents less than 1% of the stocks and they consider it “Critically Endangered” under the International Union for Conservation of Nature (IUCN) standards.

Neo and Todd (2012a, 2013) found that *T. crocea* in Singapore is “probably already functionally extinct as they are reproductively isolated and unlikely to fertilise conspecifics”.

*Tridacna derasa* has been extirpated in Vanuatu (Teitelbaum and Friedman 2008).

For *T. gigas* local extirpations have occurred in Guam, the Mariana Islands, and Federated States of Micronesia, New Caledonia, Taiwan, Ryukyu Islands and Vanuatu (Teitelbaum and Friedman 2008). Tan and Yasin (2003) found that *T. gigas* was extirpated from Malaysia; Kittiwattanawong et al. (1997) found the same in Thailand. Munro (1992) reports their extirpation from the Federated States of Micronesia, and from Taiwan, Japan, Vanuatu and probably New Caledonia. He also found that *T. gigas* is functionally extinct in Indonesia and Philippines waters and possibly also in southern Myanmar/Burma. Neo and Todd (2012a, 2013) show that *T. gigas* is extirpated in Singapore. Poorten (2007) reports on the results of the Rumphius expedition to Ambon Indonesia; the primary objective of the expedition was to collect marine invertebrates on the localities mentioned by Rumphius (1627-1702) in his book "D'Amboinsche Rariteitkamer" (1705). All of the cardiid bivalves collected in 1705 still occurred in the area in 1990, except *T. gigas*.

Neo and Todd (2012a, 2013) found that *T. maxima* is “probably already functionally extinct as they are reproductively isolated and unlikely to fertilise conspecifics”.

*Tridacna squamosa* is functionally extinct from Samoa and Singapore (Zann and Mulipola 1995, Neo and Todd 2012a, 2013).

*Hippopus hippopus* has been extirpated in Fiji, Tonga, Samoa and American Samoa, Guam, The Mariana Islands, Singapore, and Taiwan (Wells 1996a, Skelton et al. 2002, Teitelbaum and Friedman 2008, Neo and Todd 2012a, 2013). Eliata et al. (2003) report on surveys of Pari Island Indonesia from 1984 and 2003. *H. hippopus* declined 84%.

Other studies reported on the abundance and population trends of the Tridacninae fauna of specific islands and these are discussed below to provide geographic and community ecology contexts.

Tan and Yasin (2003) document that there are six giant clams found in Malaysian waters: *Tridacna crocea*, *T. derasa*, *T. maxima*, *T. squamosa*, *Hippopus hippopus* and *H. porcellanus*. *Tridacna crocea* is the only species in Malaysia that had a stable population by the early 2000s, while the others are considered to be endangered there. *Tridacna gigas* is already extinct in Peninsular Malaysia and *H. porcellanus* and *T. derasa* are restricted to Sabah, Eastern Malaysia.

In Singapore, Neo and Todd (2012a, 2013) found that *H. hippopus* and *T. gigas* are presumed extinct nationally, while they categorize *T. maxima* and *T. squamosa* as critically endangered and *T. crocea* as endangered. They do note that “The latter three species are probably already functionally extinct as they are reproductively isolated and unlikely to fertilise conspecifics” (Neo and Todd 2013).

In the Philippines, Villanoy et al. (1988) examined average size frequency distributions of *Tridacna squamosa*, *T. gigas*, *Hippopus hippopus* and *H. porcellanus* harvested from the Sulu Archipelago and Southern Palawan areas from 1978–1985. Estimates of exploitation rates indicate that populations of these species are already overexploited. These findings have serious implications in view of the fact that the Sulu Archipelago and Southern Palawan are thought to be the last strongholds of giant clams in Philippine waters. Alcala (1986) documented abundance in the South Central Philippines but there are no trends. Doloros and Schoppe (2005) found that densities of *H. hippopus* and *T. crocea* had declined significantly in Tubbataha Reef Park in the Philippines since the early 1990s. *Tridacna crocea* decreased from 2,200,000/km<sup>2</sup> in 1993 (Calumpong and Cadiz 1993) to 1,000,000/km<sup>2</sup> in 1995 (Ozoa 1995), and to 133,330/km<sup>2</sup> in 2005; a decline of 94%. Dolorosa and Schoppe (2005) similarly found that the decline in *H. hippopus* density from 1995 to 2005 was 97%. They also found that *T. squamosa* densities were much lower than elsewhere in the Philippines. They found no *T. gigas* at all though the species is native to the region.

Brown and Muskanofola (1985) found that *T. gigas* and *H. hippopus* were locally extinct in Indonesia while *T. derasa* had only 1 individual and was thus functionally extinct. Also in Indonesia, Hernawan (2010) found small populations and evidence of recruitment failure in the six species found during a survey of Kei Kecil, Southeast-Maluku, namely *Tridacna crocea*, *T. squamosa*, *T. maxima*, *T. derasa*, *T. gigas*, and *Hippopus hippopus* (one Indonesia species not found). Juvenile or adult *T. gigas* and *T. derasa* were only found in one of nine study sites.

Kittiwattanawong (1997) report four species of giant clams in the Andaman Sea of Thailand: *gigas*, *crocea*, *maxima* and *squamosa*. They note *T. gigas* has been extirpated since the early 1990s and live *T. squamosa* were very rare. Chantrapornsyl et al. (1996) also document heavy exploitation and local extirpation of *T. squamosa* in the Andaman Sea. In Mo Ko Surin National Park in Thailand *T. crocea* was still abundant in the late 1990s but *T. maxima* was already rare, *T. squamosa* was nearing extinction, and *T. gigas* and *H. hippopus* were considered extinct (Talaythai 2001). Thamrongnavasawat et al. (2001) report that *T. squamosa* and *T. maxima* are now considered “scarce” throughout Thailand.

Overfishing of giant clams in Japan led to a reduction in catch from 578 tonnes in 1975 to just 28 tonnes in 1995, indicating a potentially large decline there (Okada 1997).

Lucas (1994) reports local extinction in many islands in Micronesia, largely due to overfishing.

Despite the small known population size of *T. tevoroa*, a “concentrated effort was made to collect as many broodstock specimens of this new species in Tonga as possible and to transport these to the hatchery” (Ledua et al. 1993). A total of 62 were collected in Tonga from 1989-1992 (and 14 in Fiji) at a collection rate of ~ 1/hr (Ledua et al. 1993). The average from Fiji was 0.26/hr (Ledua et al. 1993). An old diver from Uiha Island, Ha'apai, Tonga reported that he saw or collected *T. tevoroa* clams in 3 m of water in the 1940s; and clams were seen in small clumps at that time (Ledua et al. 1993), supporting the notion that the species has declined significantly in accessible waters. Their current abundance is likely less.

Hardy and Hardy (1969) did a seminal study of ecology of *Tridacna* in Palau in the 1960s where they found six species: *Tridacna gigas*, *T. derasa*, *T. squamosa*, *T. maxima*, *T. crocea*, and *Hippopus hippopus*. In random transects, *T. crocea* was the most frequent and abundant, while *T.*

*derasa* and *T. gigas* made up the largest proportion of the standing crop biomass because of their size. Hester and Jones (1974) recorded densities of 50 *T. gigas* and 33 *T. derasa* per hectare at Helen Reef, Palau before these stocks were totally decimated by distant-water fishing vessels. This is a remote atoll halfway between the main island of Palau and Indonesia. There is no evidence they have recovered.

In 2004, the first no-take area dedicated to the conservation of giant clams *Tridacna maxima* was implemented in Tatakoto Atoll, French Polynesia. This preserve protected a unique area worldwide, with extraordinarily high giant clam densities (up to 337 individuals per m<sup>2</sup> on 20-m transects). However in 2012, a stock assessment survey revealed a dramatic decrease of the clam population. The reduced densities peaked at 38/m<sup>2</sup> and the stock in the preserve decreased from 20.1 ± 6.0 million to 1.9 ± 0.55 million clams (mean ± 95% confidence interval)[with the 2004 abundance likely below historic levels already]. Losses of similar proportions were observed throughout the atoll. The 83% overall loss of this natural resource is likely due to high temperature in 2009 (Andrefouet et al. 2013). Gilbert et al. (2006) found high population sizes but a new and growing fishery for *T. maxima* in French Polynesia which corroborates the work of Andrefouet et al. (2013).

Chambers (2007) notes that *T. maxima* and *T. squamosa* are the only two giant clams in the Cook Islands. *Tridacna maxima* was overharvested in the southern Cook Islands and the capital was now receiving them from the northern part of the country. She also showed both density data and historical accounts supporting overharvesting close to villages in the main remaining abundant island and at increasing distances in recent years as the market has increased.

I have already discussed the situation in China and the South China Sea disputed area (above) where recent media stories report on massive fishing efforts and habitat destruction by Chinese fisherman searching for giant clams, partly to replace ivory now that bans on their trade are being enforced (BBC 2015, Grind TV 2015, Bale 2016, Diplomat 2016, Larson 2016). A main target is the giant clam (*Tridacna gigas*). Given the threats discussed elsewhere in this report for Asia and here for the South China Sea, it is likely that *T. noae* has also declined severely.

In sum, all of the species of giant clams have undergone significant declines from natural abundances throughout all or a significant portion of their range.

## CONSERVATION STATUS

Nine of the species of Tridacninae were considered and ranked by the IUCN Red List in 1996 (the others (*noae* and *costata*) are more recently described). All of the IUCN assessments are thus far far out of date, even by the IUCN's own standards, and much new information is available as I have already documented (see above). Therefore I won't even bother to cite the IUCN status. Richter et al. (2008) propose "Critically Endangered" as the appropriate category for the new species *T. costata* that was not evaluated by the IUCN. This species used to make up 80% of the giant clams in its range but now represents less than 1% of the stocks (Richter et al. 2008).

Neo and Todd (2013) reassessed the status of giant clams in Singapore using the IUCN standards and currently *H. hippopus* and *T. gigas* are presumed extinct nationally, while they categorize *T. maxima* and *T. squamosa* as critically endangered and *T. crocea* as endangered. They do note

that “The latter three species are probably already functionally extinct as they are reproductively isolated and unlikely to fertilise conspecifics” (Neo and Todd 2013).

All giant clams are also listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) because of trade-related threats (see below).

As I have documented above in the Population Structure and Abundance and Population Trends sections, all of the giant clams have been severely reduced in their ranges. All of the species that have been studied show population substructuring that further threatens their conservation status and maintenance of genetic diversity. Global and local threats (see full discussion below) from demand in trade and subsistence, global climate change, inadequate regulatory mechanisms, inherent life history limitations, and negative effects on habitat mean there are no parts of their range that are protected or secure and no evidence of long-term stable and sustainable populations.

## **THREATS**

I discuss the five ESA threat categories next as well as interactive and synergistic threats as required. Giant clams face all of the regular threats on coral reefs of coral reef habitat degradation (Chou 1999, Guest et al. 2008, Brainard et al. 2011), sedimentation and pollution (Roberts et al. 2002), subsistence harvesting by coastal and island communities (Munro 1989, Kinch 2002), commercial harvesting and the sale and export of wild specimens for the meat, aquarium, and curio trade (Wells 1997, Wabnitz et al. 2003) with illegal trade and poaching a major problem (Lucas 1994). They also face threats from global climate change and bleaching of their symbiotic zooxanthellae (Brainard et al. 2011) and ocean acidification affecting their shells.

Some studies have documented threats for all giant clams at the national or regional level. Neo and Todd (2012b) show the main threats in Singapore are overexploitation, sedimentation, and habitat loss through land reclamation. They believe densities are so low intervention is required to successfully restore the species. Richter et al. (2008) had the opportunity to examine human impacts throughout the history of human occupation of the Red Sea. They document drastic changes in species composition and an over 70% decline in shell umbo thickness over time (Figure 3).

A similar paleontological study in Fiji from the Lapita era (1100-550 BC) found that valve size/weight of *H. hippopus* increased with depth (age) in the shell middens (Seeto et al. 2012), suggesting that human harvest contributed to its disappearance there. They were able to date the extirpation to about 750 BC. Climate-driven sea level changes were also implicated in the extirpation.

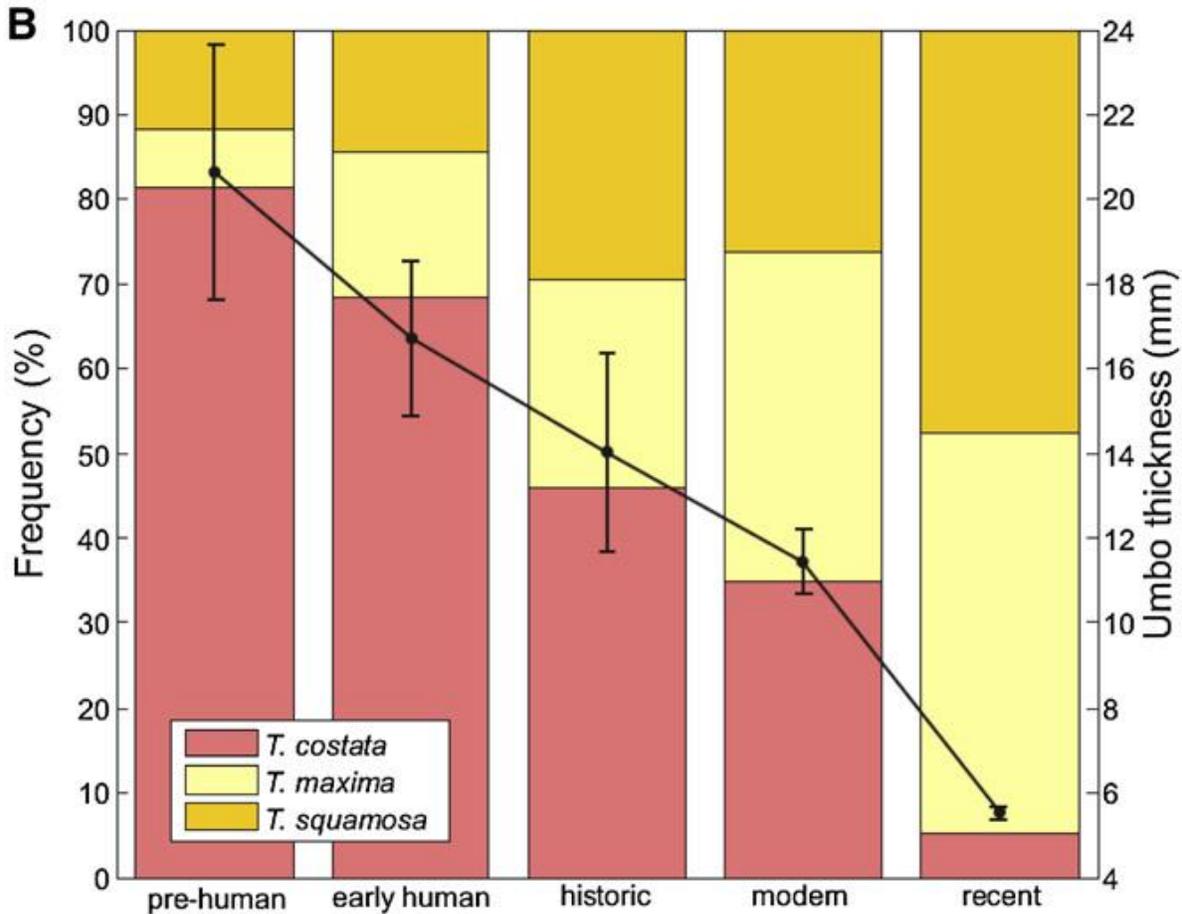


Figure 3. Species composition (stacked bars) and mean size (umbo thickness SEM, line) of three species of *Tridacna* in various stages of human occupation of the Red Sea (pooled data from Aqaba and Nabeq). From Richter et al. (2008).

### PRESENT OR THREATENED DESTRUCTION, MODIFICATION OR CURTAILMENT OF HABITAT OR RANGE

Giant clams inhabit shallow coastal waters which are highly vulnerable to habitat degradation caused by various anthropogenic activities (Foster and Vincent 2004). Brainard et al. (2011) and Meadows (2014) document habitat destruction issues throughout the range of these species and that information is incorporated herein by reference.

Bale (2016) reports that satellite imagery analysis shows over 40 square miles of giant clam habitat on coral reefs in the South China Sea have been destroyed by giant clam poaching which uses explosives, tools of various sorts, and/or dragging and pulling to remove giant clams from the surrounding habitat. These techniques all destroy the surrounding coral reef and other habitat structure. Another 22 square miles of giant clam habitat in the South China Sea has been destroyed by island-building and dredging activities, mostly by the Chinese government (Bale 2016).

Neo and Todd (2012b) document sedimentation and habitat loss through land reclamation affecting all giant clam species in Singapore.

Elfwing et al. (2001) found that copper decreased photosynthesis and sedimentation increased activity and metabolism of *T. squamosa* from the Gulf of Thailand, effects that could cause added stress or mortality to giant clams wherever such stressor exist.

## **OVERUTILIZATION FOR COMMERCIAL, RECREATIONAL, SCIENTIFIC OR EDUCATIONAL PURPOSES**

Giant clams are highly vulnerable to stock depletion because of their late sexual maturity and essentially sessile adult phase (Munro 1989). Densities can rapidly decline with exploitation (Gomez and Alcalá 1988).

Giant clams, specifically their adductor, gonads, muscles and mantle tissue, are used for food (bin Othman et al. 2010). Their shells are used for jewelry, ornaments, soap dishes, salad bowls, and floor tiles (Usher 1984). The shells of this species are considered a desirable luxury item and are thought to confer supernatural powers and improve health in China (Diplomat 2016). The Chinese website Alibaba has 2 dozen pages devoted to giant clam products for sale. A pair of high quality shells sells for \$150,000 (Diplomat 2016).

Harvest is both for subsistence purposes and part of a large network of global international trade. Moreover trade is increasing; Larson (2016) noted a number of forces at play in the proliferation of the giant clam industry, including improved carving techniques, Hainan, China's popularity with tourists, the growth in e-commerce and the domestic Chinese wholesale market. There is concern that recent clamp down's on trade in ivory products has diverted attention to giant clam shells (McManus 2016). This is clear just by looking at the products available for sale as the carvings look like ivory carvings (e.g., <https://world.taobao.com/item/39520343928.htm?fromSite=main&spm=a312a.7728556.w4023-7931277905.2.mXhCS>). As with ivory, the products include beads, bracelets, paperweights, etc. Moreover, the shape of the large giant clam shells makes them highly desirable for making large, intricately carved scenes.

Commercial fisheries have included long-range Taiwanese fishing vessels that goes back 50 years or more as well as more local fisheries that developed in the 1970s and 1980s in Papua New Guinea, Fiji, and the Maldives (Munro 1992). Commercial fisheries also developed in the Philippines, Japan (including their deep water fleet), the Cook Islands, Micronesia, and Vietnam (Lucas 1994, Chambers 2007, bin Othman et al. 2010). More recent commercial fisheries have developed in China with long-range vessels (see above discussion and BBC 2015, Grind TV 2015, Bale 2016, Diplomat 2016, Larson 2016). In 2012 the Chinese government encouraged the development of Tanmen's fishery for giant clams. The efforts are closely involved in China's efforts to construct military and commercial outposts in the disputed islands of the South China Sea. The industry supports 100,000 people in Tanmen alone (Cavell 2016). The number of boats fishing for giant clams has grown in Tanmen from 3-4 to dozens in the past 5 years, each capable of collecting hundreds of shells a day (Cavell 2016).

Current and historic overutilization has been documented for many of the giant clam species and throughout their range. I first discuss multi-species studies, then single species study's by taxonomy and then chronologically below. Ashworth et al. (2004) studied reef-top gathering inside and outside of MPAs in Egypt. Gathering of molluscs on the reef-top, largely by women, is part of the traditional fishery practiced by Bedouin in South Sinai, Egypt. The catch is dominated by *Tridacna spp.* and *Octopus spp.* Within the Nabq Managed Resource Protected

Area, on the southern Gulf of Aqaba coast, a network of no-take zones (NTZs) was established (in 1995) to promote sustainable management of finfish stocks. Pooled data from all three years showed significantly higher abundances of *Tridacna* in the NTZs, with greater abundances occurring at the reef edge zone. Size–frequency distributions revealed both a greater size range of *Tridacna* and a greater mean size of *Tridacna* within the NTZs, as compared to the fished areas. The low clam abundance (live and dead) in the shallowest and most easily accessible areas of the reef flat, combined with small sizes, strongly suggest artisanal reef-top gathering for meat and shells of the native *Tridacna spp.* in the northern Red Sea of Egypt (Ullmann 2015).

In the Philippines, Villanoy et al. (1988) examined average size frequency distributions of *T. squamosa*, *T. gigas*, *H. hippopus* and *H. porcellanus* harvested from the Sulu Archipelago and Southern Palawan areas from 1978–1985. Estimates of exploitation rates indicated that populations of these species were already overexploited then. These findings have serious implications in view of the fact that the Sulu Archipelago and Southern Palawan are thought to be the last strongholds of giant clams in Philippine waters. Rubec et al. (2001) document that three species (*Tridacna gigas*, *T. deresa*, and *Hippopus porcellanus*) have been depleted and are no longer commercially harvestable in the Philippines.

Rubec et al. (2001) note that most populations of giant clams are over-fished throughout Southeast Asia.

Tan and Yasin (2003) found that of the 6 species in Malaysian waters (*Tridacna crocea*, *T. derasa*, *T. maxima*, *T. squamosa*, *Hippopus hippopus* and *H. porcellanus*) only *T. crocea* (the smallest and most cryptic) had stable populations at that time. All the others are endangered. *Tridacna gigas* is extinct in peninsular Malaysia and *H. porcellanus* and *T. derasa* are restricted to Sabah, Eastern Malaysia. Whether *T. crocea* is currently still stable is unknown. They list geological uplift, poaching, and bomb fishing as threats. They also note that the shells used to be so common they were used as a construction material and picture one structure in their paper.

Lucas (1994) reports local extinction of *Tridacna spp.* in islands in Micronesia, largely due to overfishing. Lucas (1994) lists four main reasons for giant clam overfishing in recent times in Micronesia: increased human population, improved technology available to subsistence fishermen, expanded international/inter-island trade and poaching of giant clam meat, and expanded international trade in shell specimens and artifacts.

Hester and Jones (1974) recorded densities of 50 *T. gigas* and 33 *T. derasa* per hectare at Helen Reef, Palau before these stocks were totally decimated by distant-water fishing vessels. There is no evidence they have recovered.

Overfishing of giant clams in Japan led to a reduction in catch from 578 tonnes in 1975 to just 28 tonnes in 1995, indicating a potentially large decline there (Okada 1997).

Richter et al. (2008) show a decline in shell size of 20-fold(!) in Sinai and Aqaba Red Sea, indicative of overharvesting in *T. costata*.

*Tridacna crocea* has been overfished in Fiji, Japan and Vietnam (bin Othman et al. 2010).

The Fijian fishery for *T. derasa* landed a total over 218 tons over a nine year period, with the largest annual harvest totaling 49.5 tons and which is thought to have removed most of the

available stock (Lewis et al. 1988). The fishery in Papua new Guinea was closed after removal of at least 85 tons of adductor muscle over a five year period, equivalent to over 750 tons total flesh weight.

Bodoy (1984) found that harvesting decreased the size of *T. maxima* in Saudi Arabia. The study by Shelley (1989) discussed above documented likely overfishing of *T. maxima* in the Cook Islands based on a very low proportion of mature individuals in the population. Chambers (2007) notes that *T. maxima* was overharvested in the southern Cook Islands and the capital was now receiving them from the northern part of the country. She also showed both density data and historical accounts supporting overharvesting close to villages in the main remaining island that had abundant populations and at increasing distances in recent years as the market has increased for commercially fished clams.

As noted above, Chantrapornsyl et al. (1996) documented heavy exploitation and local extirpation of *T. squamosa* in the Andaman Sea of Thailand.

At the Lapita-era (1100-550 B.C.) settlements (Bourewa and Qoqo) along the Rove Peninsula in Fiji, shells of *Hippopus hippopus* (long extirpated in Fiji) occur in shell middens. Valve size/weight increase with depth (age) in the midden, suggesting that human predation contributed to its local disappearance (Seeto et al. 2012).

## **INADEQUACY OF EXISTING REGULATORY MECHANISMS**

There are no existing regulatory mechanisms at the international, federal, or state level which adequately protect giant clams or the habitat they need to survive. I discuss national harvest protections below and then separate subsections consider international trade and greenhouse gases.

There are some protections for giant clams on the books. Under Fisheries Administrative Order No. 208 series of 2001, all seven species of giant clams in the Philippines are listed as endangered (Dolorosa and Schoppe 2005), but as documented above declines continue and areas of the Philippines also claimed by China in the South China Sea are not being protected. Hundreds of giant clams were confiscated from Chinese fishermen who poached in Tubbataha Reef National Marine Park, Philippines. Records collected by Ticke (2002) state 200 *T. gigas* while Benavent-Villena and Pido (2004) discuss 30 sacks of dried giant clams confiscated (Dolorosa and Schoppe loc cit. 2005). Filipino fishermen have also recently been arrested for giant clam poaching (Diplomat 2016).

Tan and Yasin (2003) found that The Malaysian Department of Fisheries has listed giant clams as a protected species. They however note poaching is a threat and continued declines and functional extirpation.

Vietnamese fishermen have also been arrested for giant clam poaching (Diplomat 2016).

In disputed areas of the South China Sea the evidence shows that illegal giant clam fishing has occurred in the presence of both the Chinese Navy and Coast Guard (Diplomat 2016), showing that the domestic Chinese regulations that exist are not enforced.

I personally witnessed giant clam poaching by Asian vessels on the Great Barrier Reef of Australia in 1987.

### **Regulation of Trade is Inadequate**

The entire Tridacnidae family of giant clams (see above discussion of current taxonomy) was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1985. All Appendix II- listed taxa can still be traded internationally, but shipments must include CITES documentation that verifies that the species were obtained legally and that international trade is not detrimental to the persistence of wild populations. In the United States, CITES is implemented primarily by the U.S. Fish and Wildlife Service (FWS), though the Service works collaboratively with the National Marine Fisheries Service (NMFS). Inspectors from the FWS are stationed at 15 designated ports throughout the country, and process over 100,000 shipments each year (Bruckner et al. 2005). Importers and exporters must purchase a standard wildlife import/export license each year, and pay fees to process each shipment they receive at a U.S. port. Approximately 25 percent of all wildlife shipments are inspected, and the inspections may cover the entire shipment or just selected specimens (Bruckner et al. 2005). In most of the rest of the world inspection rates and enforcement are even lower. Thus not all illegal shipments are intercepted and smugglers often simply incorporate the likelihood of seizures in their costs of business. Listing under CITES does not effectively protect giant clams for this reason and others discussed below.

There are wide disparities in yearly giant clam trade figures (CITES 2004a, b, c, d) that suggest that some countries have failed to exert control on the clam trade (bin Othman et al. 2010). Many instances of domestic and international poaching and failure to enforce harvest protections were documented above.

Shang et al. (1991, 1994) evaluated the existing market for giant clam products in Japan, Taiwan, Hong Kong, Australia and the United States. They found that markets exist for five types of giant clam products: food, aquarium specimens, seed stock, broodstock and shell. The largest potential market for giant clam products appears to be as food. At the time, the food market in Okinawa could absorb up to 500 t of giant clams, mainly for use as sashimi and sushi dishes. People in Okinawa prefer *T. crocea*. In Taiwan, a market for fresh or frozen giant clam adductor muscle existed with a potential of about 240 t annually (at that time). A limited market potential existed for giant clams as aquarium specimens in Japan, Australia and the United States. The market for giant clam shells appeared good. Larson (2016) documents increased demand in China for *Tridacna* shells for use in scrimshaw after crackdowns on illegal ivory trade (see above). A pair of high quality shells sells for \$150,000 (Diplomat 2016). There have been no wider recent market analyses but the status information and information on current harvest pressures strongly suggest market demand has increased.

### **Regulation of Greenhouse Gases is Inadequate**

There are no existing regulatory mechanisms which protect giant clams from the threat posed to its habitat and survival by global climate change. Climate change and its effects including bleaching and ocean acidification represent the most significant long-term threat to the future of global biodiversity. Sea level rise, stronger and more frequent hurricanes, and higher storm surge also all threaten giant clams or their habitat and changes in these threats have been linked to climate change (Knutson et al. 1998, Easterling et al. 2000, Scavia et al. 2002, Komar and Allan 2008).

To avoid catastrophic climate change, most experts agree greenhouse gas emissions must be significantly reduced, but the United States has not enacted the necessary regulatory mechanisms that would require such reductions. Current voluntary commitments have no regulatory certainty as they are not required to be implemented. Current warming and the warming commitment “in the pipeline” already constitute “dangerous” climate change with regard to species and ecosystems (Warren 2006, Hansen et al. 2008, Lenton et al. 2008, Jones et al. 2009, Smith et al. 2009, IPCC 2013). The United Nations’ Intergovernmental Panel on Climate Change (IPCC) Reasons for Concern reflect that current warming is already at a point where significant risks to species and ecosystems are occurring, and that these risks will become “severe” at a  $\sim 1^{\circ}\text{C}$  rise above preindustrial levels (Smith et al. 2009). The continuation of the current global emissions trajectory, which is tracking the most fossil-fuel intensive projection of the IPCC (Richardson et al. 2009), would increase the Earth’s temperature by an average of  $4^{\circ}\text{C}$  by the end of the century (IPCC 2007).

The IPCC released the fifth global assessment report in 2013 (IPCC 2013). This report provides increased certainty from earlier reports regarding the role of human sources in causing global climate change and showed with high confidence that ocean warming accounts for over 90% of the energy accumulated in the global climate system between 1971 and 2010. The report concluded that about 30% of the emitted anthropogenic  $\text{CO}_2$  has been absorbed in the oceans.

Hansen et al. (2008) concluded that the safe upper limit for atmospheric  $\text{CO}_2$  needed to avoid ‘dangerous climate change’ is at most 350 parts per million (ppm). They found that our current  $\text{CO}_2$  level has committed us to a dangerous warming commitment of  $\sim 2^{\circ}\text{C}$  temperature rise and is already resulting in dangerous changes. Hansen et al. (2008) concluded that the overall target of at most 350 ppm  $\text{CO}_2$  must be pursued on a timescale of decades since paleoclimatic evidence and ongoing changes suggest that it would be dangerous to allow emissions to overshoot this target for long. Veron et al. (2009) determined 350ppm was a critical limit for corals most similar to tridacninae clams.

Current atmospheric carbon dioxide is at over 400 ppm and worldwide emissions continuing to increase by more than 2 ppm each year, rapid and substantial reductions are clearly needed immediately to protect giant clams.

## **DISEASE AND PREDATION**

There is no evidence that levels of predation have changed or are unnaturally high and affecting the status of giant clam populations (except for humans as discussed above). Diseases, however, have been documented in a number of species and cannot be ruled out as a threat, especially as the natural origin and rates of many diseases are unknown and it is well known that diseases have increased with climate change and with general stress on populations (Roessig et al. 2004).

Goggin and Lester (1987) studied *Perkinsus* protozoans of bivalves on the Great Barrier Reef. *Perkinsus* cause mass mortalities in many species of bivalves, including commercially important species such as oysters. The study found that giant clams were the third most frequently infected family of 23 families of bivalves. Goggin and Cannon (1989) found the turbellarian *Urastoma cyprinae* in *T. gigas* throughout Australia, with unknown effects. Alder and Braley (1989) report a sudden mortality of *T. gigas* and *T. derasa* at two sites near Lizard Island, Australia that reached 32-38% of the populations and may have been caused by a unicellular organism never

seen at those sites before. Norton et al. (1993) found mortality in *H. hippopus* from rickettsiales-like organisms in the western Pacific.

*Turbonilla sp.* is a small pyramidellid gastropod that is an ectoparasite on *T. gigas*. In field surveys of an intertidal culture site at Orpheus Island, Great Barrier Reef, 9–17% of the juvenile clams were found to be infested with *Turbonilla sp.*, and this occurred in an aggregated pattern (Boglio and Lucas 1997). Growth experiments showed that the parasites were lethal in cases of heavy infestations on juvenile clams, and that they reduced clam growth in sublethal infestations. Reduction in growth rate was related to clam size and number of parasites. The estimated total losses of linear growth rate and productivity of infected clams were 2.8–4.2% and about 7%, respectively.

## **OTHER NATURAL OR ANTHROPOGENIC FACTORS**

Several other factors threaten giant clams including their life history features that make them vulnerable to decline and slow to recover. Giant clams are very slow to recover because of their late sexual maturity and sessile adult phase which requires proximity to at least one potential mate (see above and Munro 1989). For example, Salazar et al. (1999) did a stock assessment of *T. crocea*, *T. maxima*, *T. squamosa* and *H. hippopus* in the Eastern Visayas of the Philippines and found most of the populations were juveniles with insufficient numbers of breeders to repopulate the region. Similarly, Neo et al. (2013) modelled recruitment of *T. squamosa* in Singapore and concluded that poor fertilization rates “indicate that the low density and scattered distribution of the remaining *T. squamosa* in Singapore are likely to significantly inhibit any natural recovery of local stocks”.

### **Global Climate Change and Bleaching**

Climate change and its effects on giant clam biology and habitat, especially through bleaching and ocean acidification effects on corals and giant clams, is a major threat. These effects are caused by the rapid increase in atmospheric concentrations of greenhouse gases that are in turn increasing the radiative forcing of the global climate system and altering ocean carbonate chemistry.

Bleaching occurs when the photosynthetic zooxanthellae symbionts are damaged by light at higher than normal temperatures. The resulting damage leads to the expulsion of these important organisms from the host, depriving the host of the nutrients and energy provided by the zooxanthellae. Bleaching events have been increasing both in intensity and geographic extent due to worldwide anthropogenic climate change (Hoegh-Guldberg 2006, Eakin et al., 2009).

Just like stony corals (Brainard et al 2011), the *Symbodium* zooxanthellae in giant clams are subject to bleaching and other effects from high temperature. See Brainard et al. (2011), 77 FR 73219, and 79 FR53852 for a full discussion of these threats, which is to be incorporated by reference herein in its entirety for its effects on corals that form giant clam habitat and for the implications for effects on giant clams that carry the same type of symbiotic zooxanthellae (Leggat et al. 2003, Sangmanee et al. 2010). These high temperatures are part of an overall trend in global temperature as well as periodic events such as El Niños (Brainard et al. 2011). According to NOAA's Coral Reef Watch, the global experts in bleaching events, we are currently in the longest and most extensive coral bleaching event in earth's history (Coral Reef Watch

2016). It is the worst ever bleaching event recorded in some parts of the range of giant clams (e.g., the Great Barrier Reef and Kiribati) and bleaching has occurred in areas where it never has before.

Increased sea surface temperatures in Southeast Asia (Guest et al. 2012) was specifically linked to giant clam bleaching (Ishikura et al. 1999).

The mass bleaching event affecting corals and giant clams in 1997–1998 in the Great Barrier Reef (GBR, Australia) inspired a number of studies on giant clams. Buck et al. (2002) investigated the effects of high light intensities and increased temperature accompanied by nutrient limitation on the metabolism of *T. gigas*. They did this to test if these environmental changes can induce bleaching and whether high light intensities can induce changes in chlorophyll content or alter zooxanthella cell sizes and populations in the tissue. After 50 days of exposure to high light intensity similar to the bleaching event, the mantle tissue of stressed clams exhibited a decreased number of zooxanthellae per unit area from  $19.8 \pm 0.8$  to  $0.2 \pm 0.2$  (mean  $\pm$  CL). Additionally, the average cell size of zooxanthellae decreased from  $7.4 \pm 0.1$   $\mu\text{m}$  to  $5.3 \pm 0.1$   $\mu\text{m}$  (mean  $\pm$  CL). Chlorophyll content, both chl a and chl c1, declined severely: chl a from  $192 \pm 4$  to  $0.1 \pm 0.1$   $\mu\text{g/ml}$  and chl c1 from  $145 \pm 6$  to  $0$   $\mu\text{g/ml}$  (mean  $\pm$  CL). This study thus shows that increased light intensity and temperature are the main causes for bleaching in giant clams, just as in corals.

Leggat et al. (2003) found that the zooxanthellae in *T. gigas* declined 30-fold during the 1998 global coral bleaching event. They studied details of the metabolic processes affected and found that this decline in zooxanthellae resulted in significant increases in haemolymph inorganic carbon and decreases in haemolymph pH and glucose concentration, the predominant photosynthate exported from zooxanthellae in this symbiosis. In other words, without zooxanthellae symbionts, the clams lost the nutrition they provided in ways very similar to the effects on stony corals (see Brainerd et al. 2011). The clam's ability to assimilate ammonium was also eliminated in bleached individuals (Leggat et al. 2003), further stressing them.

During the high sea surface temperature event in June 2010, local bleaching of *Tridacna squamosa* in Singapore was observed (Neo and Todd 2013).

Lucas et al. (1989) studied the effects of emersion (which often exacerbates effects of other stressors) on growth and survival of juveniles of *T. gigas* at Orpheus Island, Australia. Juvenile clams tolerated up to 10 h per day mean emersion, but were completely stunted in growth.

Blidberg et al. (2000) studied the effect of increasing water temperature  $3^{\circ}\text{C}$  on *T. gigas*, *T. derasa* and *H. hippopus* in the Philippines. *Tridacna gigas* had the highest metabolic rate and was least sensitive to heat stress. The two *Tridacna* species both reduced gross production and decreased respiration in response to the temperature increase, while *H. hippopus* increased respiration and production. In a similar study, *T. squamosa* increased respiration but decreased production in response to temperature change (Elfwing et al. 2001).

Watson et al. (2012) found that *T. squamosa* juvenile survival decreased up to 80% with increasing pCO<sub>2</sub> and decreased with increasing seawater temperature for a range of temperatures and pCO<sub>2</sub> combinations that mimic those expected in the next 50-100 years.

Ocean acidification threatens to slow or halt coral growth and reef building entirely if the pH of the ocean becomes too low for corals to form their calcite skeletons (see Brainard et al. 2011, Meadows 2014). In addition, bioerosion of coral reefs and giant clam skeletons is likely to accelerate as skeletons become more fragile as a result of the effects of acidification.

Waters (2008) found that *T. maxima* juveniles exposed to pCO<sub>2</sub> concentrations approximating glacial (180 ppm), current (380 ppm) and projected (560 ppm and 840 ppm) levels of atmospheric CO<sub>2</sub> (per the IPCC IS92a scenario) suffered decreases in size and dissolution and this occurred “well below thresholds previously considered detrimental to other marine organisms in similar conditions”. The work by Andrefouet et al. (2013) on *T. maxima* discussed above further documents temperature induced mortality in French Polynesia.

Lin et al. (2006) found that *T. gigas* had by far the lowest compressive and flexural shell strength as compared to other large molluscs (abalone and queen conch); compressive strength was 1/3 to 1/2 that of the other species. This suggests any loss of shell material or strength from the effects of ocean acidification may have a greater negative effect on giant clams than other large molluscs.

Sea-level is also likely to rise as a result of climate change, but effects on corals and giant clams are highly uncertain owing to uncertainty in both the likely rate and extent of sea-level rise as well as the ability of corals and giant clams to keep pace with the rise in sea level (Brainard et al., 2011).

Brainard et al. (2011) emphasize the underlying ultimate causal factor for these anthropogenic threats deriving from climate change is human population growth and affluence.

## **SYNERGYSTIC EFFECTS**

Elfwing et al. (2003) compared disturbed sites, where *T. gigas* had experienced multiple stressors, including both natural turbidity and impacts from human settlement and fish pens, to reference site. After 6 months there were significantly lower values for both wet weights (wwt) and shell lengths (SL) at the “disturbed sites”.

Recent research has shown that synergistic interactions among threats often lead to higher extinction risk than predicted based on the individual threats (Brook et al. 2008). “Like interactions within species assemblages, synergies among stressors form self-reinforcing mechanisms that hasten the dynamics of extinction. ... Together, these interacting and self-reinforcing systematic and stochastic processes play a dominant role in driving the dynamics of population trajectories as extinction is approached” (Brook et al., 2008). Similar synergistic effects are likely here as well. For example, climate change may indirectly magnify disease as discussed above as well as coastal pollution and other problems. Because of water circulation and oceanic volume changes, estuarine and coastal systems are predicted to experience “increased eutrophication, hypoxia, and anoxia” (Roessig et al. 2004). For most of these giant clam species it is possible that the interactive effects of the numerous threats identified herein are having multiplicative effects on extinction risk. In particular, habitat loss, climate change, and harvest may interact in ways to multiplicatively increase the extinction risk of these species, especially so as populations reach such small sizes where Allee effects, genetic drift, and disasters can dominate population dynamics.

## CONCLUSION

The Endangered Species Act requires that NMFS promptly issue an initial finding as to whether this petition “presents substantial scientific or commercial information indicating that the petitioned action may be warranted.” 16 U.S.C. § 1533(b)(3)(A). There is no question, listing these giant clams may be warranted. They are in decline or extirpated throughout their ranges, are not panmictic, and are threatened by loss or curtailment of habitat or range, overutilization, inadequacy of existing regulatory mechanisms, and various other factors. The life history traits of giant clams further render the species vulnerable to decline and slow to recover. For these giant clams to have the best chance at recovery, they should be promptly protected under the Act and given the critical habitat they need to survive.

## REQUEST FOR CRITICAL HABITAT DESIGNATION

Petitioners urge NMFS to designate critical habitat for all of these species that occur in waters subject to U.S. jurisdiction concurrently with its listing under the ESA because of the serious nature of the threats to the species. Critical habitat as defined by Section 3 of the ESA is: (i) the specific areas within the geographical area occupied by a species, at the time it is listed in accordance with the provisions of section 1533 of this title, on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) the specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provisions of section 1533 of this title, upon a determination by the Secretary that such areas are essential for the conservation of the species. 16 U.S.C. § 1532(5).

Congress recognized that the protection of habitat is essential to the recovery of listed species, stating that: classifying a species as endangered or threatened is only the first step in insuring its survival. Of equal or more importance is the determination of the habitat necessary for that species’ continued existence... If the protection of endangered and threatened species depends in large measure on the preservation of the 40 species’ habitat, then the ultimate effectiveness of the Endangered Species Act will depend on the designation of critical habitat. H. Rep. No. 94-887 at 3 (1976).

Critical habitat is an effective and important component of the ESA, without which these giant clams chance for recovery diminishes. Species with critical habitat are twice as likely to be recovering compared to species lacking designated habitat (Taylor et al. 2005). Petitioner requests that NMFS propose critical habitat for these species concurrently with its proposed listing.



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