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Growth and population dynamics of the giant clam *Tridacna maxima* (Röding) at its southern limit of distribution in coastal, subtropical eastern Australia

STEPHEN D. A. SMITH
National Marine Science Centre, Southern Cross University, PO Box 4321, Coffs Harbour, New South Wales, 2450, Australia.
Email: ssmith@nmsc.edu.au

Abstract

The Solitary Islands Marine Park in northern New South Wales hosts eastern Australia's southernmost coastal population of the giant clam *Tridacna maxima*. This small population of clams was monitored and measured over a 12-yr period to determine patterns of distribution, dynamics and growth rates. Most (31) of the 40 specimens found were present at the most offshore location (North Solitary Island) and growth rates were similar to those recorded on the southern Great Barrier Reef. Recruitment rates were very low (<2 yr^{-1} across the whole Park) and loss of individuals was mostly associated with periods of large swell. The importance of North Solitary Island for *Tridacna* reflects the results of other studies demonstrating a strong tropical influence, mediated by the East Australian Current, at this, the most offshore island on the NSW coast.

Key words: Bivalvia, Cardiidae, North Solitary Island, Solitary Islands Marine Park, subtropical reef

Introduction

With a distribution throughout the Indo-Pacific region, *Tridacna maxima* (Röding, 1798) (Bivalvia: Cardiidae: Tridacninae) is the widest ranging of the tridacnine clams (Munro 1993) (Fig. 1). While this species is often highly abundant on tropical reefs (McMichael 1974; Lucas 1994; Andrefouet *et al*. 2005, 2009; Gilbert *et al.* 2006) and is a common feature of communities on the subtropical reefs of Lord Howe Island (S 31º 33′, E 159º 04′) (Hutton and Harrison 2004), until this study, the southern distribution limit for coastal, eastern Australia was deemed to be south-eastern Queensland (a specimen from off Moreton Island – S 27 º 12′, E 153 º 21′—AM C. 338507). The presence of *T. maxima* at the Solitary Islands, however, is not surprising given the strong tropical affinity of benthic and fish communities in this region (Veron *et al.* 1974; Harriott *et al.* 1994; Malcolm *et al.* 2010a, b), and the array of other tropical molluscs that have been recorded, especially from the outer islands (Smith 2001). Indeed, the sporadic occurrence of *T. maxima* has been documented (sometimes photographically) by a succession of dive operators over the last 30 years, especially at North Solitary Island (NSI), the most northerly and furthest offshore of the Solitary Islands group (Fig. 2).

FIGURE 1. A medium-sized specimen of *Tridacna maxima* at a depth of ~6 m at Anemone Bay, North Solitary Island.

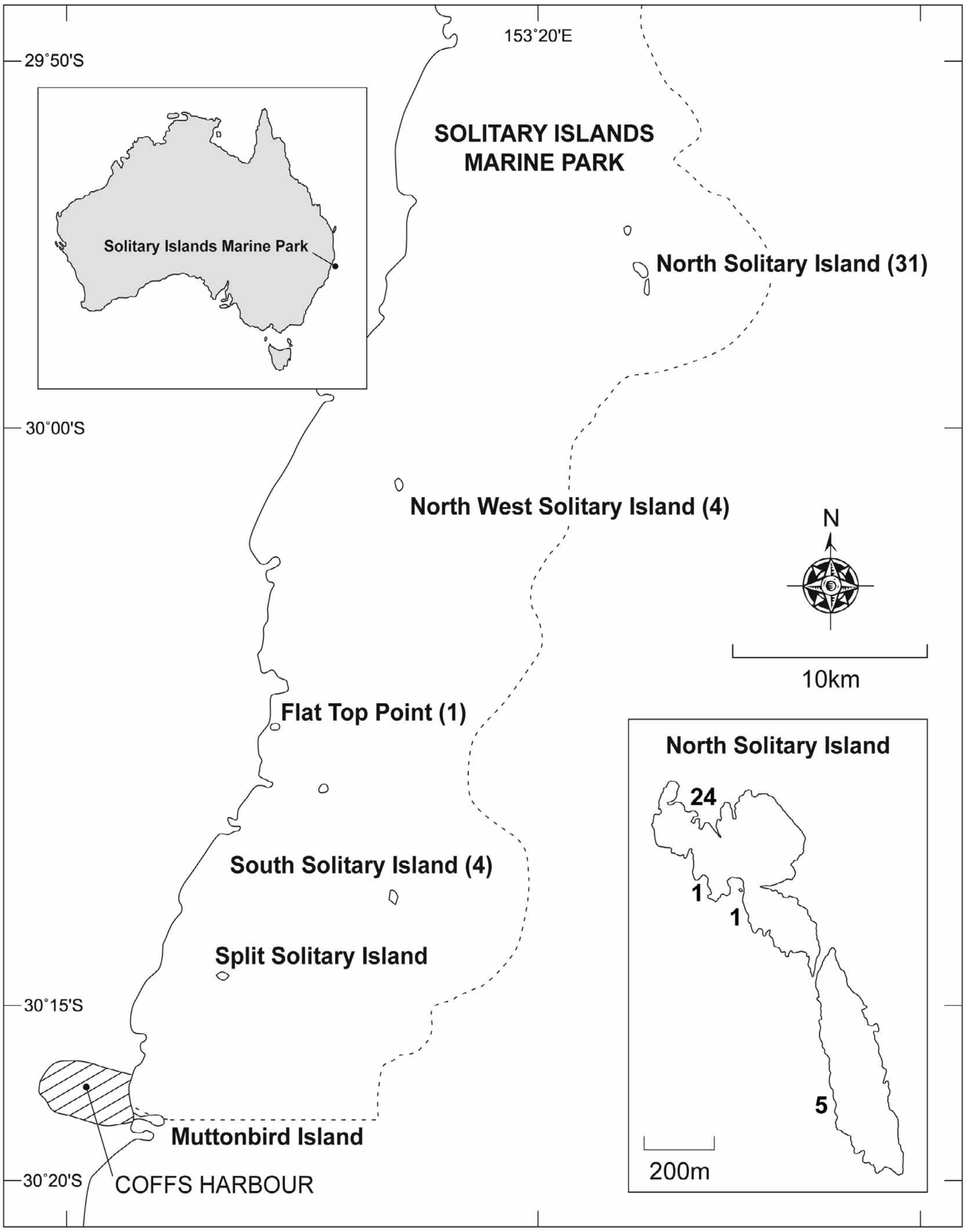

FIGURE 2. Map of the Solitary Islands region showing the locations of *Tridacna maxima* sightings and their cumulative abundance (in brackets) over surveys conducted between 1997-2009. Inset - North Solitary Island showing the predominance of sightings (24) in Anemone Bay at the northern end of the island.

A broad-scale search in 1997 determined that *T. maxima* were present at a number of subtidal island locations within the Solitary Islands Marine Park (SIMP), and one small specimen was also found in an intertidal rock pool within the region (Smith 2001). These observations prompted further surveys in subsequent years which indicated that clams were persistent, particularly at a sheltered site at NSI. For this reason, a population study was commenced which involved marking and annual measurements , and searches for new recruits at as many sites as possible. The specific objectives of the study were to examine the distribution, growth rates and spatial and temporal dynamics of this southernmost coastal population.

Materials and methods

Initial searches for clams at subtidal sites at NSI indicated that they occupied a narrow depth range (~3–8 m) in areas with some protection from the predominant south-easterly swell. For this reason, yearly searches were performed on suitable shallow fringing reefs on the leeward sides of the major islands within the SIMP. Searching in other habitats (e.g. intertidal rock-pools on coastal headlands) and on more exposed sections of reef, was conducted opportunistically. In addition, and primarily because of the large area of shallow reef fringing the main islands, search effort was increased by encouraging local and visiting divers to report sightings that could later be verified (this generated seven new observations over the duration of the study). When found, clams were recorded onto site maps and measured (maximum length) to the nearest millimetre using Vernier callipers. Surveys were repeated yearly from 1997 to 2009 during the austral winter (July to August each year). Yearly growth was estimated for each marked clam and any new sightings/recruits were mapped, measured and sought-out in subsequent years. Yearly growth increments of marked clams were assessed using a Ford-Walford plot from which the parameters for the Von Bertalanffy growth curve (L∞ and K) were derived (e.g. Degraer *et al.* 2007). These parameters were then compared to those measured across a range of geographical locations from published records. Although the total population size over the 12-year period was small, population dynamics were evaluated by looking at yearly recruitment and survival rates of individual clams over time.

Results

Distribution and turnover rates

A total of 40 specimens of *Tridacna maxima* was recorded between 1997-2009. The overwhelming majority (31) of these were found at NSI, with 24 occurring in a small protected section of a single bay—Anemone Bay (Fig. 2). *T. maxima* was distributed across a narrow depth range (2.9–7.9 m) with almost half found in 5–7 m and only four specimens below 7 m. Although it is difficult to provide definitive assessments of such a small population, recruitment rates and persistence clearly differed between sites (Table 1) (note that this assessment was only made for clams that recruited and were lost from the population during the period of observation). Average recruitment rates, persistence and, consequently, size at loss, were all highest at Anemone Bay. Recruitment rates at other sites for which there was sufficient data were substantially lower (Table 1).

Size and growth rate

The size of live clams ranged from 31–236 mm; the dead valves of a smaller specimen were also found on one occasion (22 mm—this specimen was deposited in the Australian Museum, voucher number C.339047). The majority of clams were first detected when they reached a size of ~50 mm. While juvenile tridacnine clams are notoriously difficult to observe during subtidal surveys, the brightly coloured mantle of *T. maxima* makes it more observable than some of the other species (Munro 1993). However, most shallow reefs in the SIMP have complex topography at small scales as fleshy macroalgae, coralline algae and carpets of zoanthids occupy up to 100% of space in the depth-range recorded for clams (see zoanthid cover in Fig. 1). For this reason, settled individuals were mostly found only once they protruded above this benthic cover. There was only one exception to this pattern, an individual measuring 31 mm (at Anemone Bay) which measured 56 mm the following year. Based on observations elsewhere, individuals of ~50 mm are likely to be 2-3 years old (Solis *et al.* 1988; Munro 1993). At the extremes of their range, clams are known to spawn over short periods in the summer (Munro 1993). As larvae reaching the SIMP probably originated from the southern Great Barrier Reef and/or Coral Sea (Booth *et al.* 2007) it is highly likely that most recruitment occurs in summer. Thus, because the present surveys were conducted in winter, individuals measuring ~50 mm are likely to be 30–42 months old.

TABLE 1. Population size, mean recruitment rate (to a size of ~50 mm), mean persistence (years since first observed) and mean size when lost from the population from all sites where clams were found. NSI—North Solitary Island; NWSI—North West Solitary Island; SSI—South Solitary Island. * = insufficient data.

Site	N	Recruitment rate (yr^{-1})	Persistence (yr) (no. records)	Mean size when lost (mm)
Anemone Bay (NSI)	24	1.27	4.2 (13)	126.7
NSI (other sites)	7	0.36	3.0 (2)	104.0
NWSI (all sites)	4	*	*	*
SSI (all sites)	4	0.36	*	*
Flat Top Point	1	*	< 1	*

The predicted maximum size of clams in the SIMP (L = 269 mm—Table 2) falls within the range reported from other Pacific sites and is similar to values for populations at One Tree Island, southern Great Barrier Reef (GBR) (McMichael 1974). Surprisingly, growth rates, as estimated by K (Table 2) were higher than for the One Tree Island population.

Discussion

It is clear from these data that NSI not only supports the highest density of clams but also that the population within Anemone Bay is the most persistent. There are a number of probable reasons for this. Firstly, it is highly likely that clams arrive as larvae carried by the East Australian Current as has been hypothesised for a range of other tropically-affiliated biota (Harriott *et al.* 1994; Booth *et al.* 2007). As the outer island in the Solitary Islands group, and the most-offshore island on Australia's east coast, the reefs associated with NSI are more frequently bathed in Eastern Australian Current-derived waters (Malcolm *et al.* 2011) and thus more frequently available for recruitment of entrained tropical larvae. The primary site for *T. maxima*, Anemone Bay, is also one of the most sheltered locations at any of the islands. This arguably contributes to the diversity of relatively fragile taxa (e.g. some corals) (Harriott *et al.* 1994) and is likely to lead to the persistence of clams, even in shallow waters (<4 m). By contrast, the other offshore island, South Solitary Island (SSI), regularly experiences considerable wave exposure; the site where the four clams were found during this study was a small, shallow section of reef on the most sheltered (north-western) aspect. Finally, both water temperature (Malcolm *et al.* 2011) and average water clarity (although this has not been quantified) are greater at offshore islands. These factors are likely to provide conditions that will facilitate both growth and survival of *Tridacna* (e.g. Klumpp *et al.* 1992).

For corals, one of the factors thought to limit community development at high latitudes is the putatively lower growth rates that are partly a result of lower water temperatures (Harriott 1999; Lough and Barnes 2000; Harriott and Banks 2002). While this study failed to find evidence of lower growth rates for *T. maxima* in comparison to tropical populations, it did reveal an important parallel with coral dynamics. One of the main factors hypothesised to restrict coral accretion at high latitudes is the relative frequency of extreme wave exposure removing coral from the substratum (Harriott and Banks 2002). Loss of clams in the present study was also associated primarily with episodes of heavy swell. The most graphic example of this was the succession of East Coast lows in March-May 2009 which removed seven of the 12 clams present in Anemone Bay in 2008 and reduced the SIMP-wide population from 16 to eight. Loss on this scale was unprecedented over the duration of the study.

TABLE 2. Summary of Von Bertalanffy growth parameters for *Tridacna maxima* from different studies.

Location	L_∞	K	Author
Solitary Islands, NSW	269	0.118	This study
Motupore Island, Papua New Guinea*	243	0.28	Munro and Gwyther 1981
Tonga	305	0.082	McKoy 1980
Papua New Guinea	305	0.112	Munro and Heslinga 1983
One Tree Island, Great Barrier Reef	275	0.074	McMichael 1974
Takapoto lagoon, French Polynesia	124	0.260	Richard 1981
Rose Atoll, Samoa	278	0.1	Green and Craig 1999

*Under aquaculture conditions

This small study has confirmed a number of patterns evident in other work looking at tropical influence in the SIMP. Thus, coral species richness (Harriott *et al.* 1994) and tropical representation in fish assemblages (Malcolm *et al.* 2010a) are both higher at NSI compared to other sites. In addition, densities of host anemones and anemone fish are substantially higher at NSI than at any other site in subtropical eastern Australia (Richardson *et al.* 1997). It is highly likely that further investigation will reveal similar patterns for lesser-studied members of shallow-water communities, confirming the importance of this island for representing regional biodiversity.

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