Controlling predators of cultured tridacnid clams. [Conference paper]

Controlling Predators of Cultured Tridacnid Clams

H. Govan*, L.Y. Fabro† and E. Ropeti§

SURVIVAL of cultured juvenile giant clams in the ocean nursery phase is reported to be relatively low, ranging from as low as 40% over the first 2.5 years for *Tridacna gigas* stocked at six months of age (Barker et al. 1988) to 50–75% over four years for one year old *T. derasa* (Heslinga et al. 1990). Much of this mortality can be attributed to predation.

Many animals are known to be capable of preying on juvenile tridacnids (Govan 1993) but most are not usually abundant or are excluded by properly closed ocean-nursery cages and therefore are not serious obstacles to giant clam culture.

Ranellid gastropods of the genus *Cymatium*, parasitic pyramidellids and, possibly, stylochid flatworms are the most serious pests found so far as they are difficult to control (Govan 1993). Other predators commonly reported include muricid gastropods and xanthid, portunid and diogenid crabs.

Cymatium muricinum (Gastropoda: Ranellidae) has previously been reported as a serious pest of cultured tridacnid clams (Perron et al. 1985). This species and also *C. aquatile*, *C. nicobaricum* and *C. pileare* are found throughout the tropical Pacific and are serious pests at almost all locations where tridacnids are cultured in ocean-nurseries (Govan 1992). They are difficult to control because they are capable of settling out of the plankton in clam cages at an early stage in their life cycle. Larger individuals represent a serious threat because of their nocturnal habits, ability to locate clams easily and ability to kill rapidly and consume even relatively large clams.

As part of an international collaborative study of predators of cultured giant clams some aspects relevant to the reduction of clam losses due to predation have been studied at the Coastal Aquaculture Centre of the International Centre for Living Aquatic Resources Management (ICLARM CAC), Silliman University Marine Laboratory (SUML) and the Fisheries Division of Western Samoa (WSFD). The aspects discussed in this paper are: the effects of cage location and design and the vulnerability of different clam species to predation by the gastropods *Cymatium pileare*, *C. muricinum* (Ranellidae), *Chicoreus palmarosae* (Muricidae) and *Bursa granularis* (Bursidae) and the crustaceans *Atergatis floridus* (Xanthidae), *Carpilius convexus* (Xanthidae), *Thalamita danae* (Portunidae) and *Dardanus pedunculatus* (Diogenidae).

Methods

Prey choice experiments

In the first series of prey choice experiments (performed at SUML) three gastropod and four crustacean predators were offered four species of clam (*Tridacna derasa*, *T. maxima*, *T. crocea*, and *Hippopus hippopus*). Three similar-sized individuals of each predator were tested individually in 80 litre flow-

* ICLARM Coastal Aquaculture Centre, PO Box 438, Honiara, Solomon Islands.
† Silliman University Marine Laboratory, Dumaguete City, Negros Oriental, Philippines.
§ Fisheries Division, PO Box 1874, Apia, Western Samoa.

through aquaria. Five byssally attached individuals of each prey species were placed in aquaria with individual predators. Dead clams were counted and removed daily but not replaced. Two size classes of clam prey were tested; small (10–30 mm shell length, SL) and medium (30–60 mm SL). Control aquaria were also maintained containing clams but no predators. No mortality was observed in these aquaria. Most experiments lasted for eight weeks.

Prey consumed were not replaced, thereby progressively requiring the predator to consume subsequent prey in order of preference over the duration of the experiments. Data from this experiment were expressed as an accumulative ranking similar to the method used by Morton (1990). Data from the three replicates for each predator were pooled. The first individual prey chosen by a predator species was allotted a number equivalent to the total number of prey consumed by that predator species, the second individual prey was allotted that number minus one and so on until the last prey individual chosen which was accordingly allotted the number one. Summing of the numbers for each species gives an approximate indication of overall prey preference as shown by Morton (1990).

In the second series of preference experiments (performed at ICLARM CAC) two tridacnid species, *T. gigas* and *H. hippopus* (40–50 mm SL) were offered to the predator, *C. muricinum*, in 24 litre flow-through aquaria. Five byssally attached specimens of each clam species were placed in aquaria with individual predators. Dead clams were counted, removed and replaced daily, experiments lasted from 2–3 weeks. Predators in these experiments were starved for one week prior to the start of the experiment.

Two experiments were conducted, one with four adult specimens of *C. muricinum* (mean size 43.8 mm) and one with eight juveniles (mean size 20.6 mm). No controls were maintained but similar or higher densities of clams were kept in similar aquaria during the course of the experiment and no mortalities were observed.

Use of trestles in ocean-nurseries

Eight 0.7 m^2 cages containing 400 juvenile *H. hippopus* (mean length 32 mm) and 400 *T. gigas* (mean length 41 mm) were placed in an ocean-nursery at Namu'a, Western Samoa. Four cages (two containing *H. hippopus* and two containing *T. gigas*) were placed directly on the sand bottom. The remaining cages were raised 0.8 m off the seabed on trestles in an attempt to reduce the incidence of benthic predators, principally *Cymatium* spp. and *Chicoreus* sp. Clams were measured and counted every month for three months and predators were collected during routine, usually nocturnal patrols.

Exclusion of ranellids from cages

Cage mesh size: Laboratory observations of the genus *Cymatium* at ICLARM CAC suggested that these snails could penetrate cage meshes provided the minimum diameter of the snail was less than the mesh aperture. In order to determine the optimum mesh sizes needed to exclude predatory snails from cages, measurements were made of four species commonly found preying on clams in ocean-nurseries, namely *C. muricinum*, *C. aquatile*, *C. pileare* and *C. nicobaricum*. The length and minimum diameter of 15 individuals of each species ranging from early juvenile to adult were recorded.

Trestle leg excluders: A variety of devices were designed to prevent snails from climbing the legs of trestles used to raise cages above the seabed. Designs included: inverted cones of various materials, bundles of tangled mesh, bundles of sharp bristles, groups of horizontal disks at different spacings, cones with polythene skirts, suspension of cages on fine wires and combinations of the above. These devices were tested in 2000–5000 L tanks. Starved *C. muricinum* were placed in the tanks with clams in trays on trestles. Trestle legs were fitted with various devices. Five prototypes of the most successful device were further tested in similar tanks. Clams were placed on top of the devices which were suspended in the tanks. Snails were placed in trays attached to the bottom end of a rod simulating a trestle leg passing through the device. The snails had no option other than staying in the tray or climbing up into the device. In all these trials dead clams were replaced daily.

Results

Prey choice experiments

During the first series of prey choice experiments the methods of attack of the different predators were observed. The crustaceans; *Atergatis floridus* (purple and grey colour morphs), *Carpilius convexus*, *Dardanus pedunculatus* and *Thalamita danae* crush or chip the valves of their prey although the latter species also attacks through the byssal orifice if this is exposed. The gastropods *Cymatium pileare* and *Bursa granularis* attack by inserting their proboscii between the valves of their prey and at least in the former species toxic salivary secretions may be used. *Chicoreus palmarosae* often drills through the valves of the prey although attacks may take place through the valve gape or byssal orifice.

The results of the first series of prey choice experiments expressed as accumulative rankings are shown in Table 1 for small clams, and in Table 2 for medium-sized clams. Of the species offered *T. derasa* was generally the preferred or most susceptible prey and *H. hippopus* was the least consumed prey for both small and medium-sized clams. Although there is variation between predator species this trend is apparent for both gastropod and crustacean predators and is more marked for small clams. This overall order of preference or susceptibility is maintained whether accumulative ranking, total number of clams consumed or simple ranks are considered (Table 3). *T. crocea* and *T. maxima* occupy an intermediate position with no clear ranking being apparent.

Results of the *H. hippopus* and *T. gigas* prey choice experiments are shown in Tables 4 and 5. Both large and small *C. muricinum* consumed far more *T. gigas* than *H. hippopus*. Variation in numbers of clams consumed by the snails was high. Adult snails consumed on average 0.5 clams/day regardless of species, whereas small snails consumed an average of 0.3 clams/day. On occasion some of the *T. gigas* became byssally detached but all attacks were observed to take place between the valve gape and not through the byssal orifice.

Table 1. Results of a tridacnid prey choice experiment in which predators were offered four species of 10–30 mm SL clams, expressed as sum of accumulative rankings[a].

Predator	Size (cm)	*T. derasa*	*T. crocea*	*T. maxima*	*H. hippopus*
Atergatis floridus (grey)	4.0 CW	203.5 (12)	213.0 (11)	154.0 (7)	24.5 (4)
Atergatis floridus (purple)	3.3 CW	417.0 (15)	314.5 (13)	321.5 (13)	378.0 (12)
Carpilius convexus	4.8 CW	343.5 (14)	248.5 (12)	242.5 (10)	200.5 (9)
Dardanus pedunculatus	3.2 CL	270.0 (14)	365.0 (11)	286.0 (12)	114.0 (8)
Thalamita danae	4.9 CW	417.0 (14)	411.0 (14)	448.5 (14)	319.5 (14)
Bursa granularis	3.8 SL	418.5 (15)	268.5 (11)	248.0 (10)	241.0 (12)
Chicoreus palmarosae	9.2 SL	529.0 (15)	235.5 (9)	249.0 (12)	261.5 (14)
Cymatium pileare	6.7 SL	347.0 (13)	295.0 (14)	74.0 (7)	103.5 (6)
Totals		2945.5 (112)	2351.0 (95)	2023.5 (85)	1642.5 (79)

[a]Numbers in brackets are total number of clams consumed. Mean predator sizes are shown. CL = cheliped length; CW = carapace width; SL = shell length.

Table 2. Results of a tridacnid prey choice experiment in which predators were offered four species of 30–60 mm SL clams, expressed as sum of accumulative rankings[a]

Predator	Size (cm)	*T. derasa*	*T. crocea*	*T. maxima*	*H. hippopus*
Atergatis floridus (grey)	4.0 CW	27.0 (5)	64.0 (8)	0.0 (0)	0.0 (0)
Atergatis floridus (purple)	3.3 CW	187.5 (10)	42.0 (4)	116.5 (9)	215.0 (10)
Carpilius convexus	4.8 CW	308.5 (13)	308.5 (12)	426.0 (13)	85.0 (9)
Dardanus pedunculatus	3.2 CL	39.0 (5)	59.0 (4)	16.0 (4)	96.0 (7)
Thalamita danae	4.9 CW	487.0 (15)	286.5 (14)	379.5 (13)	122.0 (8)
Bursa granularis	3.8 SL	7.5 (3)	13.0 (2)	7.5 (2)	0.0 (0)
Chicoreus palmarosae	9.2 SL	328.5 (11)	78.5 (5)	305.5 (14)	233.5 (10)
Cymatium pileare	6.7 SL	104.5 (8)	157.0 (9)	38.5 (5)	135.0 (7)
Totals		1489.5 (70)	1008.5 (58)	1289.5 (60)	886.5 (51)

[a]Numbers in brackets are total number of clams consumed. Mean predator sizes are shown. CL = cheliped length; CW = carapace width; SL = shell length.

Table 3. Order of preference of seven species of predator for four tridacnid species[a].

	30–60 mm SL clams				1–30 mm SL clams			
	Td	Tc	Tm	Hh	Td	Tc	Tm	Hh
Atergatis floridus (grey)	2	1	3.5	3.5		2	1	34
Atergatis floridus (purple)	2	4	3	1		1	4	32
Carpilius convexus	2.5	2.5	1	4		1	2	34
Dardanus pedunculatus	3	2	4	1	1	3	1	24
Thalamita danae	1	3	2	4		2	3	14
Bursa granularis	2.5	1	2.5	4		1	2	34
Chicoreus palmarosae	1	4	2	3		1	4	32
Cymatium pileare	3	1	4	2		1	2	43
Totals	1	3	2	4		1	2	34

[a] Td, *T. derasa;* Tc, *T. crocea;* Tm, *T. maxima;* and Hh, *H. hippopus*, based on accumulative rankings presented in Tables 1 and 2.

Table 4. Consumption of two species of tridacnid clam, *Tridacna gigas* and *Hippopus hippopus*, offered to adult *Cymatium muricinum* over a 17-day period.

C. *muricinum* (mm)	No. consumed *T. gigas*	No. consumed *H. hippopus*
44	9	0
45	7	1
42	5	4
43	8	1
Totals	29	6

Table 5. Consumption of two species of *Tridacna gigas* and *Hippopus hippopus*, offered to young Cymatium muricinum over a 21-day period.

C. *muricinum* (mm)	No. consumed *T. gigas*	No. consumed *H. Hippopus*
23	9	0
20	4	0
21	4	1
21	9	1
22	8	0
22	5	0
17	5	0
18	2	3
Totals	46	5

Use of trestles in ocean-nurseries

Mortality was lower amongst clams raised off the seabed on trestles than in benthic cages (Table 6). *H. hippopus* experienced less mortality than *T. gigas* both on trestles and in benthic cages. Observations of the clams in the ocean-nursery suggested that the principle cause of mortality was predation as opposed to environmental factors as none of the batches grew slower or appeared more stressed. About twice as many predatory snails (*Cymatium* spp. and *Chicoreus* sp.) were collected from benthic cages. Predators were observed to be more abundant in cages at night. The ranellids were not recently settled juveniles.

Exclusion of ranellids from cages

Cage mesh size: The relationship between the length of four species of Ranellidae and their minimum shell diameter is plotted in Figure 1. The minimum shell diameter of these ranellids is roughly half the shell length ($Y = 0.45 X$, $r^2 = 0.97$). It is apparent from these data that all but exceptionally large snails may pass through 20 mm aperture square mesh.

In order to estimate the expected efficiency of various mesh sizes in excluding *Cymatium* spp. Size-frequency data provided by Steve Lindsay for *Cymatium* spp. recovered from benthic cages with a mesh size of 25 mm in Kosrae during 1991 are plotted in Figure 2. The mean size of the 91 snails collected was 31 mm. Based on the calculated length/diameter relationship approximateley 67% of these snails would have been excluded by 12.5 mm aperture square mesh.

Table 6. Mortality over three months of four batches of juvenile tridacnids in the Namu'a ocean-nursery[a].

	Benthic cages	Trestle cages
	Mortality (%)	
H. hippopus (30–40mm)	6.7	1.0
T. gigas (40–65mm)	12.0	8.0
	Predators—(numbers collected)	
Cymatium	19	9
Chicoreus sp.	5	3

a400 H. hippopus and 400 T. gigas were placed in four trestle cages and another 400 clams of each species were placed in four benthic cages.

Trestle leg excluders: *C. muricinum* had little difficulty in by-passing, sometimes in a question of minutes, all but two of the designs tested. Snails were highly active and perseverant whilst searching for prey and capable of maintaining contact with the devices under most circumstances. Snails were observed to experience difficulty crawling on vertical sheets of thin polythene (such as carrier bags) but the polythene soon fouled, stiffened or became detached rendering the devices unreliable.

The only design which showed promise functioned along the lines of a trap and is shown in Figure 3. This design has a removable base allowing trapped *Cymatium* to be collected and destroyed. Trials using this excluder showed that snails only successfully circumvented these devices on average 0.03 (range 0–0.07) times per day compared to 0.59 (range 0.33–1) for trestles with all other designs of excluder. Snails invariably killed clams within one day on trestles without excluders.

Discussion

Overall *H. hippopus* is the least vulnerable to predators of the clam species tested although not consistently in the case of larger clams. The range of attack methods used by predators suggests that the combination of strong shell, reduced byssal orifice, sharp valve edges and capacity to tightly close the valves confers on *H. hippopus* its greater resistance to most predators. Conversely, the relative susceptibility of *T. derasa* to these predators is probably a function of the thin valves with possibly weaker closure.

The less strongly defined order of preference detected in the case of the larger clams may in part be due to the lower numbers of clams consumed overall, which reduces the efficiency of the numerical technique employed, and also to the fact that *T. maxima* and *T. crocea* have relatively stronger shells and byssal attachment at this size than *T. derasa* and to a lesser extent *H. hippopus*.

Perron et al. (1985) showed that juvenile *H. hippopus* are significantly less vulnerable to *C. muricinum* predation than *T. gigas* or *T. derasa* for 80–95 mm SL clams. The results of the present study confirm this for *T. gigas* in the case of both small and

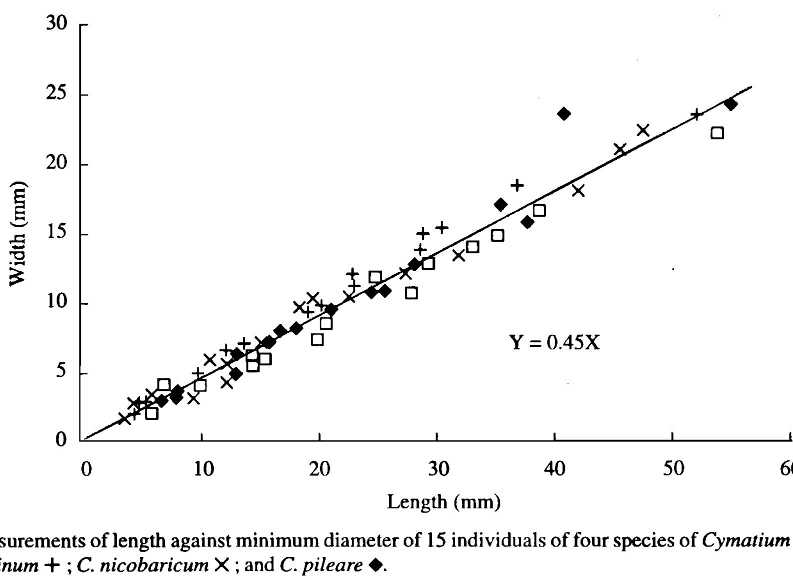

Figure 1. Plot of measurements of length against minimum diameter of 15 individuals of four species of *Cymatium* gastropod. *C. aquatile* □ ; *C. muricinum* + ; *C. nicobaricum* × ; and *C. pileare* ◆.

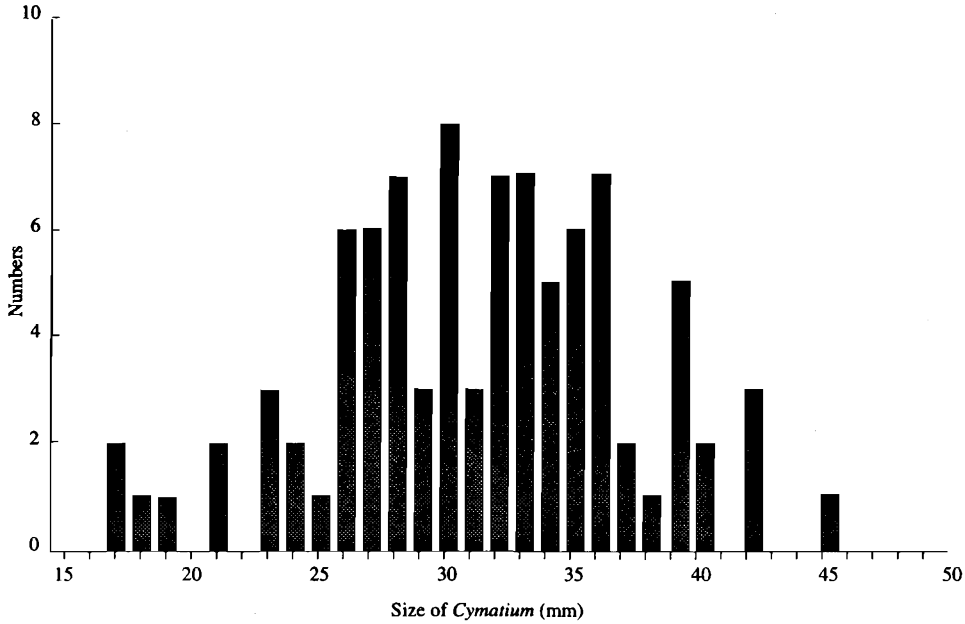

Figure 2. Size frequency of *Cymatium* snails recovered from benthic clam cages in Kosrae during 1991 (data courtesy of S. Lindsay).

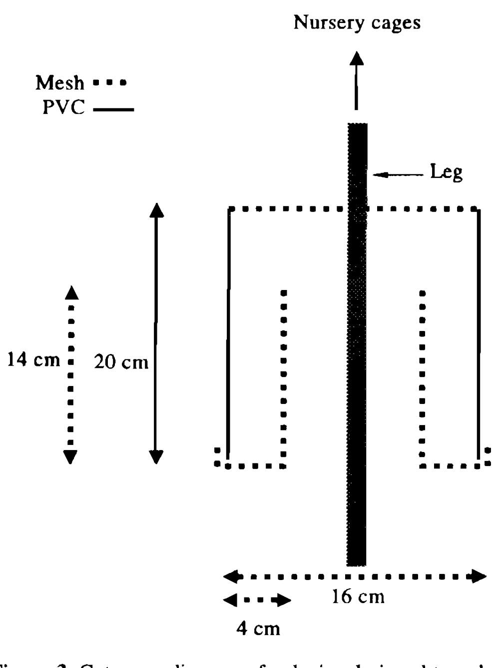

Figure 3. Cut-away diagram of a device designed to reduce the number of gastropod predators successfully climbing the legs of trestle cages in ocean–nurseries for giant clams. The excluder is made of PVC pipe with a fine mesh covering and removable base also made of mesh. The base allows trapped snails to be removed.

large *C. muricinum* although the smaller *H. hippopus* used in this study were not totally immune to attack and indeed two out of twelve snails showed no clear preference. No attacks were observed through the byssal orifice suggesting that the reason for the lower vulnerability of *H. hippopus* is not the zipper-like byssal orifice of this species as suggested by Perron et al. (1985), but more likely its capacity to close its sharper valves tightly, or possibly differences in the location of the internal organs which are the target of ranellid attacks.

The ocean-nursery trial in Western Samoa supports the contention that *H. hippopus* is less vulnerable to predation than *T. gigas*. The use of trestles apparently improved the survival of both species of clams and reduced the incidence of predatory gastropods.

Trestles do not necessarily reduce the settlement of larval ranellids although raising the cages may present more favourable hydrographic conditions for clams and less favourable ones for these larvae. Trestles do appear to hinder the attempts of adult and sub-adult ranellids to reach clam cages and these factors may account for their relative success, as found when trestles were used in Cook Islands (Sims and Howard 1988).

Trestles may be particularly useful where clam farmers determine that ranellids are entering cages from the surrounding seabed and not from the plankton.

In regularly maintained cages this is reasonably easy to determine; recently settled individuals of these species of *Cymatium* are small, thin-shelled and fragile whereas older snails resident in the ocean-nursery area may be similar in size but have thicker, heavier shells and may even possess a greatly thickened lip at the shell aperture (H. Govan, pers. comm).

Mesh sizes of about 25 mm are commonly used in ocean-nursery cages around the Pacific (Heslinga et al. 1990, Calumpong 1992) and meshes up to 50 mm square have been adopted in some locations (G. Heslinga, pers. comm.). Richardson (1991) recommended the use of 25–50 mm square meshes in ocean-nursery cages based on results obtained at Orpheus Island, Queensland. However no *Cymatium* spp. have ever been found in ocean-nurseries at this location (J. Lucas, pers. comm.). The main benefit of these large mesh sizes is the reduced surface area available to algal fouling which reduces the labour input required for its control.

The size distribution of ranellids (mainly *C. muricinum*) recovered from benthic cages in Kosrae is similar to that observed for most benthic cages in Solomon Islands. As shown in the second prey choice experiment larger snails are capable of killing significantly more clams than smaller snails.

The possibility of excluding approximately two thirds of the more voracious predators by using smaller mesh sizes would appear to merit more attention. When selecting meshes for ocean-nursery cages a variety of factors will have to be considered, including the expected abundance of ranellids, degree of algal fouling expected, availability of labour for fouling and snail control and the cost of the meshes.

The increased input of labour required to control algal fouling on smaller meshes may be offset by a reduction in the usual frequency of checks required for ranellid control. Another possible solution is the use of rectangular meshes which would be narrow enough to exclude larger *Cymatium* while providing a reduced surface area for algal fouling.

A less obvious consideration is the access to cages of naturally occurring biological control agents of predators. Portunid, xanthid and diogenid crabs and some fish have been observed feeding on pyramidellids, juvenile *Cymatium* and flatworms (H. Govan pers. comm.). The reduction of mesh size may have the undesired effect of excluding such organisms. The relative importance of all these factors can be expected to vary a great deal from site to site. If biological control agents are introduced into clam cages it may be that smaller meshes will be required to contain them.

Cymatium spp. are capable of climbing on to trestles supporting clam cages, the excluder device (Fig. 3) shows potential in reducing the numbers of snails entering such cages. This design has not yet been tested in the field but drawbacks may include the exclusion of naturally-occurring biological control agents and the cost of the devices.

Little information is available on the impact of wild biological control agents on clam predators. Work in progress suggests that it may be more effective to introduce known biological control agents into cages but more work is required on this topic.

Conclusions

H. hippopus appears to be less vulnerable to predators than other species although *H. porcellanus* and *T. tevoroa* were not tested. The relatively thin-shelled *T. gigas* and *T. derasa* were apparently the most vulnerable to predators.

Raising ocean-nursery cages above the seabed on trestles is recommended as it is likely to increase survival of clams and reduce the incidence of predators. Subject to site-specific variables and considerations of cost, several measures are available to reduce the impact of predation on clam farms, including smaller mesh sizes, different mesh shapes and devices to prevent predators ascending the legs of trestles.

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