

Population dynamics and fisheries potential of *Anadara tuberculosa* (Bivalvia: Arcidae) along the Pacific coast of Costa Rica

Amanda Stern-Pirlot¹ & Matthias Wolff²

1 Leibniz Institute for Marine Research, IfM-GEOMAR, Düsternbrooker Weg 20 24105 Kiel, Germany +49 (431) 600-4580; astern-pirlot@ifm-geomar.de

2 Centre for Tropical Marine Ecology, Fahrenheitstrasse 62 8359 Bremen; mwolff@zmt.uni-bremen.de

Received 08-IX-2005. Corrected 13-X-2005. Accepted 30-III-2006.

Abstract: The present study aims to describe the population dynamics and state of the fishery of the mud cockle *Anadara tuberculosa* (locally known as piangua) in three harvesting areas along the Pacific coast of Costa Rica (Chomes, Purruja and Rincón) and to put the results in context with this species in other Costa Rican areas as well as with other *Anadara* spp. around the globe. The study is based on a five-month sampling period from October, 2003 through April, 2004 during which monthly length frequency measurements and tagging experiments were carried out. Von Bertalanffy growth parameters, K and L_{∞} , (0.14 and 63.15, respectively) revealed a growth performance ($\phi' = 2.75$) which is in the range of reported values for this family of bivalves, indicating the accuracy of these values. Estimated exploitation rates range from 0.62 (Rincón) to 0.76 (Purruja) and exceed sustainable levels at all study sites. The strong overharvesting in these areas, also mirrored by the low average harvested cockle sizes relative to less exploited areas of Costa Rica and elsewhere, is due to the relatively small clam populations in each fishing area, the easy accessibility and the high economic importance of the species to the local resource users. If conservation measures are not implemented it is probable that *A. tuberculosa* may follow its formerly abundant and bigger sister species, *Anadara grandis* (chucheca), on its way to local extinction. Rev. Biol. Trop. 54 (Suppl. 1): 87-99. Epub 2006 Sept. 30.

Key words: *Anadara tuberculosa*, bivalve, Costa Rica, Golfo Dulce, Gulf of Nicoya, mangrove, phi prime, small scale fishery, von Bertalanffy.

Anadara tuberculosa (Sowerby, 1833) is a “blood cockle” that occurs in mangrove estuaries along the Pacific coast of the Americas from Baja California Sur, Mexico to Northern Peru and is the most important commercially harvested mollusk along this coastline (MacKenzie 2001).

In Costa Rica, *A. tuberculosa* -commonly known as the piangua- is harvested in the mangrove channels of the Gulf of Nicoya, Sierpe-Térraba and Golfo Dulce and in other smaller mangrove complexes along the Pacific coast (Fig. 1). Individuals are found at about 15cm deep in level muddy substrate among the prop roots of *Rhizophora* spp. within and around the margins of the mangroves.

Costa Rican cockle harvesters, or piangueros, travel into the mangroves daily at low tide on foot or in a small row boat and walk among the prop roots probing the mud with their hands in order to locate the cockles. When other marketable bivalves, such as *Protothaca asperrima* (almeja blanca) and *Mytella guyanensis* (mejillón chora) are encountered during piangua harvesting, they are collected as well. The species are collected in a bucket or sack, carried out of the mangroves into the channel to be rinsed, and carried back to town. The length of a workday depends on the magnitude of the tide; during neap tides piangueros usually work 2-3 h and during spring tides 4-5 h. There are an estimated 500 piangueros in Costa Rica

respectively. In the rainy season, the average rainfall is 600 mm/month and salinity in the upper gulf ranges from 14 to 30 ‰, with the lowest salinities recorded in the estuaries at river mouths. In the dry season, average rainfall is 50 mm/month and salinity ranges from 28 to 32 ‰ (Kress *et al.* 2002). Of Costa Rica's 41 292 ha of total mangrove area, 15 176 ha are found in the upper Gulf of Nicoya (Jiménez 1999). More information on the gulf's ecosystem can be found in Vargas (1995) and Wolff *et al.* (1998).

The Gulf of Nicoya is the most important commercial and subsistence fishing area in Costa Rica with fisheries primarily for shrimp and finfish such as red snapper and sea bass (Vargas 1995, Vargas and Mata 2004). A trophic model is available for this ecosystem (Wolff *et al.* 1998, Wolff 2006). There is also a small trap fishery for the blue crab *Callinectes arcuatus* and, of course, bivalve harvesting from intertidal areas. The finfish and shrimp fisheries have been in decline for the past 20 years as the number of fishermen and fishing boats has been increasing steadily (Vargas and Mata 2004). In response to this, the Costa Rican Fisheries Institute (INCOPECA) has instituted a yearly 3-month ban on finfish fishing and a complete ban on shrimp trawling in the upper gulf. There is no closed season for the bivalve fisheries in the mangrove areas except in the case of severe red tides.

Chomes is a ~300 ha mangrove-fringed estuary fed by Quebrada Cortina, an offshoot of Guacimal river, located on the eastern side of the upper Gulf between 10°2'30" and 10°4'00"N and 84°7'30" and 84°6'30" W. This is a typical mangrove estuary with a considerable tidal range (1.8-2.8 m) (Kress *et al.* 2002) in that the "front line" of mangroves, or the embankments bordering the channels within the estuary, are lined with *Rhizophora mangle*, and to a lesser extent two other *Rhizophora* species, *R. racemosa* and *R. harrisonii*. The area further inland, "behind" the *Rhizophora* species is usually dominated by *Avicennia germinans* and *A. bicolor* (Jiménez 1999). Other species present are *Laguncularia racemosa* and *Conocarpus*

erecta. Behind the mangroves to the north are man-made aquacultural ponds used for shrimp rearing and other ponds for salt extraction. The southern border of the main channel is lined with shrimp ponds that are no longer used and there are no mangroves present. Shallow water temperature in the estuary is uniform year-round (around 28 °C) (Kress *et al.* 2002).

Golfo Dulce, study sites Rincón and Purruja

Golfo Dulce is the southern-most embayment along the Pacific coast of Costa Rica, centered on 8°30'N and 83°16'W, and has an area of approximately 750 km². It is characterized as "fjord-like" in that it has a 50-70 m sill that separates the deep (>200 m) inner basin from the open ocean. The depth of the inner basin combined with this shallow sill limiting water exchange with the ocean causes anoxic conditions within the gulf to occur at depths of 60 m and below (Hebbeln *et al.* 1996). It is the only such embayment with these hydrographic characteristics in the tropical Americas and one of only four known in all of the tropics (Richards 1965). Surface salinity in the small estuaries within Golfo Dulce ranges from 0 to 25 ‰, lower on average than in the Gulf of Nicoya due to higher annual rainfall (200 mm/month Dec.-April and 500 mm/month May-Nov.) (Anonymous 2004a).

The gulf is bordered primarily by steeply sloping coastline, so there is relatively little topographic area available for mangroves to develop (Wolff *et al.* 1996). The mangroves present in Golfo Dulce are in three distinct and discontinuous regions: Rincón/La Palma, Golfito/Purruja, and Boca Rio Esquinas, and cover about 1 000 ha in total.

Rincón is a ~100 ha narrow strip of mangrove area at the mouth of the Rio Rincón in the northwest corner of Golfo Dulce that stretches between the villages of Rincón and La Palma and is backed by the steep slopes of the Osa peninsula covered with primary rainforest. There are primarily *Rhizophora* and *Avicennia* species present here, although *Rhizophora* dominates.

Purruja is a very small mangrove area (~70 ha) at the mouth of the Purruja River, which feeds into Golfito's southeast corner (Silva and Carrillo 2004, Silva and Acuña 2006). It is loosely linked to the largest mangrove estuary in Golfo Dulce—where the Coto-Colorado and Manzanillo Rivers converge south of Golfito—however piangueros from Purruja don't have access to the larger estuary and therefore restrict their collecting activities to the smaller Purruja river area. Again, the prevailing tree species here are of the genera *Rhizophora* and *Avicennia*.

Sampling

Field research was conducted at the aforementioned sites between October 1, 2003 and March 15, 2004. Each site was generally visited every four to five weeks for three to six days to carry out the necessary sampling.

Tagging experiments

Four hundred individuals of lengths 28-61 mm were collected in the beginning of November, 2003 from both Chomes and Rincón (200 from each site) to be tagged. The piangueros were rinsed and dried and a section of the periostracum near the umbo was sanded off using coarse-grained sandpaper to reveal the shell's white, calcium carbonate surface. On this surface a number was painted using oil-based paint; the paint was left to dry for about one hour after which time waterproof glue was applied over the painted number. Throughout this handling process the animals were kept in a cool and shaded place to avoid overheating while out of the mud.

After numbering, the lengths (as defined above) were measured and individuals were grouped into two sets of 100 at each site. Each set was replaced in an unenclosed area of approximately 25 m² in the mangrove. Sites for this experiment were chosen according to suitability of habitat for the pianguas and safety from theft. Pianguas collected from Rincón were relocated to a mangrove estuary near Playa Blanca, further south on the Osa Peninsula, so they could be more easily guarded.

Tagged living individuals and empty shells were recollected monthly between November, 2003 and March, 2004, measured and the living returned. After five months, 145 living individuals remained: 108 from Chomes and 37 from Rincón. In Chomes, losses were probably due either to mortality, migration or inability to relocate individuals, while in Rincón, the major loss was due to thievery, despite the above-mentioned relocation.

Length-frequencies

Monthly sampling campaigns throughout the study period were conducted at each site at regular intervals, during which 200-500 individuals each month were collected and the maximum shell length measured to the nearest 0.5 mm using a Vernier caliper with 0.05 mm accuracy. A different 'estero' within each mangrove complex was visited during each campaign and the pooled samples were considered to be representative of the mangrove complex as a whole. In Purruja, it was not possible to collect samples from the mangrove personally, so already-landed individuals were measured each month instead. The lengths of 2 000 individuals from Chomes, 1 349 from Rincón and 938 from Purruja were measured over the entire sampling period.

Data analysis

von Bertalanffy growth parameters

A. tuberculosa in this study was assumed to grow according to the von Bertalanffy growth function (VBGF) (Bertalanffy 1934) of the following form:

$$L_t = L_{\infty}(1 - e^{-k(t-t_0)})$$

where:

L_t : length at age t

L_{∞} : asymptotic length

k : growth constant (rate at which length approaches L_{∞})

t_0 : theoretical age of an animal at a length equal to zero according to the function

This original function has been modified by Pauly and Gaschütz (1979) to allow for the inclusion of seasonal variations in the growth. Since the present study only ranged over a relatively short period of five months and since seasonal differences were not pronounced during this period, the original VBGF was used. Also, since there is no specific age-length data available for *A. tuberculosa*, t_0 was set to zero for this study.

Growth-increment data was used to first estimate the VBGF parameters k and L_∞ by means of Gulland and Holt (Gulland and Holt 1959) and Munro (Munro 1982) plots, using the FAO-ICLARM fisheries stock assessment software FiSAT II (Gayaniilo 2000).

All *A. tuberculosa* from each replicate group (two in Rincón and two in Chomes) were individually measured. The replicate group was then divided into three size classes in intervals of roughly 10 mm from which the growth rates and lengths were averaged, resulting in a total of 12 growth increment groups which were then entered into FiSAT II.

The L_∞ value computed by the Gulland and Holt plot was unacceptably low to be used as a good estimate for the wild stock, as there were several harvested specimens larger than this computed value. So rather than using this value for subsequent analyses, L_∞ was estimated independently using the following empirical relationship by Froese and Binohlan (2000):

$$L_\infty = 10^{0.044 + 0.9841 \times \log(L_{\max})}$$

In the present study, L_{\max} is computed as the average length of the largest 3% of all individuals captured.

The Munro Plot, which allows for calculating k for each individual given an L_∞ , was used for a second estimate of k using the L_∞ computed using the above described method. The Munro routine calculates the k value in the following way:

$$k = (\ln(L_\infty - L_m) - \ln(L_\infty - L_r)) / (t_r - t_m)$$

where:

L_m : length at marking (initial reading)

L_r : length at recapture

$t_r - t_m$: time interval between mark (t_m) and recapture (t_r)

Each growth increment leads to an estimate of k , given L_∞ , and the variance of this estimate is computed. The mean of the k estimate and its standard error are output (Gayaniilo *et al.* 1995).

Growth performance index Phi prime (ϕ')

Phi prime (ϕ'), or "growth performance index," relates k and L_∞ for organisms that grow according to the VBGF in the following way

$$\phi' = \log_{10}k + 2\log_{10}L_\infty$$

The ϕ' values for a given species or group calculated from a number of published growth parameters has been shown to fit a narrow, normal distribution (Munro and Pauly 1983). In the present study, ϕ' was calculated and compared with values calculated from the literature on *Anadara* spp. growth as a gauge for the accuracy of the estimated VBGF parameters.

Mortality rates

Total mortality

It was assumed that mortality for *A. tuberculosa* follows the following negative exponential function:

$$N_t = N_0 \times e^{-Zt}$$

where:

N_0 : number of individuals at the beginning of time interval t

N_t : number of surviving individuals at the end of interval t

Z : instantaneous rate of total mortality per year

Zyear⁻¹ was estimated for each site from the slope of the right descending arm of a length-converted catch curve (Pauly 1983) using FiSAT II, from all months' combined length-frequency measurements at each site. FiSAT II outputs Zyear⁻¹ as well as the 95% confidence intervals surrounding Z based on the goodness of fit of the regression.

Natural and fisheries mortalities

Total mortality is comprised of two components: "natural" mortality (M); mortality due to predation, disease, etc., and "fisheries" mortality (F); mortality due to harvesting by humans, where

$$Z=M+F$$

In cases where there is no fishing pressure on a species, it can be assumed that Z=M (i.e. F=0). Because none of this study's sites met this criterion, an independent estimate of M was obtained based on the suggestion by Gayanilo *et al.* (1997) that Myear⁻¹ for bivalves can be reasonably estimated as roughly equal to k. Because exploitation and yield calculations are very sensitive to the M-value used, a sensitivity analysis was conducted with an envelope of +/- 15% around the M -value estimated.

Fisheries mortality (Fyear⁻¹) was calculated for each site separately as the difference between Z and M.

Exploitation rate

Exploitation rate (E) is the portion of total mortality due to fisheries, i.e.

$$E = F/Z$$

This ratio was determined for each study site separately using the mortality rates described above.

RESULTS

Growth-increments

Fig. 2 shows the results of the Munro plot calculation. The decrease in growth rate with size fits well to the von Bertalanffy curve (R²=0.7411). However, there were no tagged individuals smaller than 32 mm used in the growth experiment, so the curve assumed by the function to describe growth in smaller sizes may not be accurate, especially since organisms in juvenile stages are known not to follow the traditional von Bertalanffy curve. The value of 63.15 mm for L_∞ (calculated with the method described previously) was manually inputted for the calculation of k using the Munro plot. Based on this result, a k of 0.140 is used in further analyses where this input is necessary.

Total Mortality

Length-frequency distributions pooled across all months for each site (Fig. 3 A.1-A.3) were used to calculate total mortality (Z) using FiSAT II's length-converted catch curves (Fig. 3 B.1-B.3) inputting a k value of 0.140 and L_∞ of 63.15. The mean length

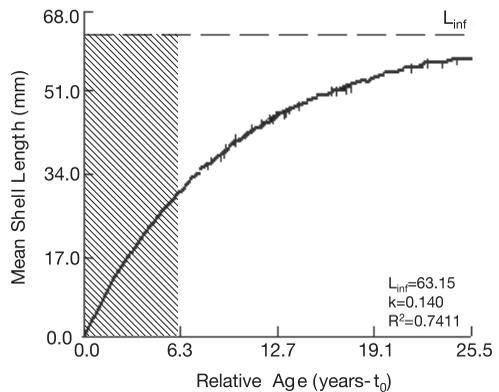


Fig. 2. Munro Plot for *A. tuberculosa* showing von Bertalanffy growth parameters k and L_∞ and goodness of fit based on growth from tagging experiments.

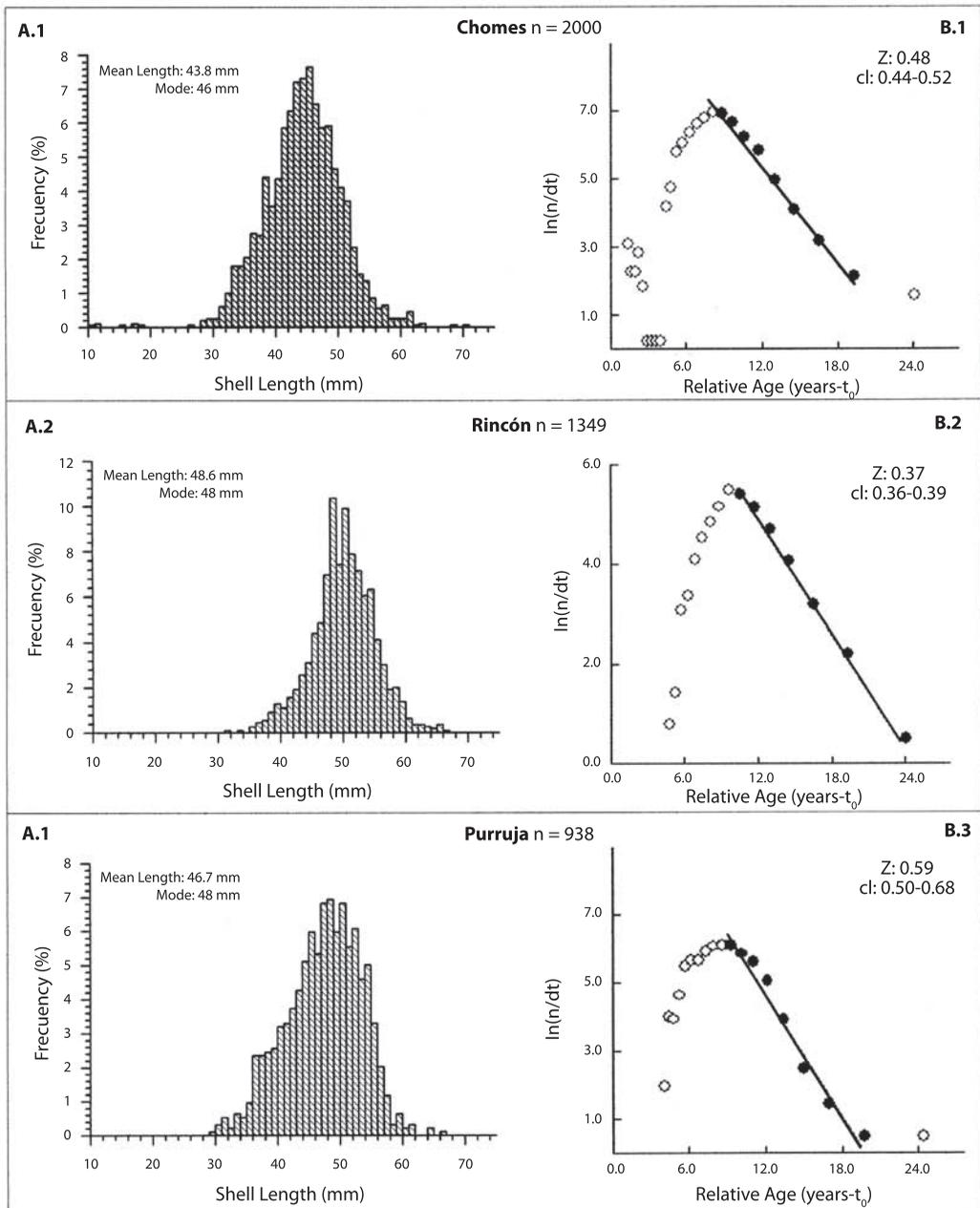


Fig. 3. A(1-3) Combined length-frequency distributions from monthly sampling at each site. B(1-3) Length converted catch curves calculated with inputs of $k=0.140$ and $L_{\infty}=63.15$. *A. tuberculosa*, Pacific coast of Costa Rica.

of harvested individuals is lowest in Chomes (43.8 mm) and highest in Rincón (48.8 mm) and all means are highly significantly different from each other (Student's t-test, $p < .0001$). 27.17%, 61.16% and 49.25% of

pianguas harvested are at or above the legal minimum harvest length of 47 mm in Chomes, Rincón, and Purruja, respectively.

Total mortality is highest for Purruja and lowest for Rincón, but only Rincón shows

a statistically significant difference from the other sites ($p < .05$).

Fisheries mortality and exploitation rate

Total mortality ($Z_{\text{year-1}}$), natural mortality ($M_{\text{year-1}}$), fisheries mortality ($F_{\text{year-1}}$) and exploitation rate (E) estimates and their corresponding confidence limits are shown in Table 1 for each study site. Additionally, the range for F and E are shown given a $\pm 15\%$ change in the estimation of M. F and E are highest for Purruja and lowest for Rincón. Assuming a lower or higher M would result in a higher or lower E, respectively, but in all cases a 15% change in the estimation of M results in F and E estimates on par with the confidence intervals.

DISCUSSION

The conventional von Bertalanffy growth model has been found to be a good description of molluscan growth (Caddy 1989, Vakily 1992), which is confirmed in the current study for *A. tuberculosa* with the goodness of fit of the growth-increment data to the VBGf (Fig. 2).

In addition, Vakily (1992) clearly demonstrated that reliable growth parameter estimates in bivalves are likely to be associated with similar

ϕ' values as long as species within the comparison group are similar in shape. Therefore ϕ' has been used in the present study to evaluate the reliability of experimentally determined growth parameters for *A. tuberculosa* by comparing ϕ' with that calculated for other similarly shaped *Anadara* species (Table 2).

Since ϕ' for *A. tuberculosa* in the present study has been found to fall within this range of 2.7 to 3.3 and is very similar to that found in the other two *A. tuberculosa* studies in Costa Rica (Madrigal 1980, Villalobos and Báez 1983), it can be reasonably assumed that the growth parameters k and L_{∞} are an accurate representation of the population under consideration.

A. tuberculosa in Costa Rica is a slow-growing species, taking roughly 25 years to reach maximum size. Twenty- to thirty-year life spans are not unusual for bivalves in general (Miller 2004). Additionally, *A. senilis* (another tropical *Anadara* species) has been shown to reach 30 years in age (Wolff *et al.* 1987, Debenay *et al.* 1994) and up to 46 year-old *A. broughtonii* have been found in Peter the Great Bay in southern Russia (Gabaev and Olifirenko 2001). Villalobos and Báez (1983) state that the individuals they used in their culture experiments were approximately 3, 4 and 5 years in age at sizes of roughly 37, 47, and 57 mm in length, respectively. This assertion is clearly in

TABLE 1
Mortality and exploitation breakdown by site for *A. tuberculosa*. Sites with different superscripts have significantly different values ($p < 0.05$ using students' *t*-test)

Site	$Z_{\text{year-1}}$	$M_{\text{year-1}}$	$F_{\text{year-1}}$ (Z-M)	E (F/Z)
Chomes ^a	0.48* (0.44-0.52)	0.14	0.34 (0.30-0.38) (0.31-0.37)	0.71 (0.68-0.73) (0.65-0.77)
Rincón ^b	0.37 (0.36-0.39)	0.14	0.23 (0.22-0.25) (0.20-0.26)	0.62 (0.61-0.64) (0.54-0.70)
Purruja ^a	0.59 (0.50-0.68)	0.14	0.45 (0.36-0.54) (0.42-0.48)	0.76 (0.72-0.79) (0.71-0.81)

*Average
(95% confidence limits)
(Range with $\pm 15\%$ change in M value)

TABLE 2
Growth-parameter comparisons for six species of *Anadara* spp.

Species	Location	k_{year}	L_{∞} (mm)	ϕ'	Authority
<i>A. tuberculosa</i>	Costa Rica	0.141	63.15	2.750	Present study
<i>A. tuberculosa</i>	Costa Rica	0.09*	75*	2.704	(Villalobos and Baez 1983)
<i>A. tuberculosa</i>	Costa Rica	0.15	59.9	2.731	(Madrigal 1980)
<i>A. granosa</i>	Malaysia	.62-1.01	41.0-53.5	3.015-3.263	(Broom 1985)
<i>A. ovalis</i>	Virginia, USA	0.45	57.5	3.173	(Mcgraw <i>et al.</i> 2001)
<i>A. senilis</i>	Mauritania	0.09**	77**	2.727	(Wolff <i>et al.</i> 1987)
<i>A. scapharca broughtoni</i>	Russia (southern Sea of Japan)	0.20-0.15	95.2-117-7	3.25-3.32	(Gabaev and Olifirenko 2001)
<i>A. corena</i>	Turkey (Black Sea)	75.24	.037	3.32	(Sahin <i>et al.</i> 1999)

* calculated from provided growth-increment data.

** calculated from provided age at length data.

contradiction with the findings of the current study and, indeed, in contradiction with their own data, evident when one looks at the growth attained in their experiment over one year (see Table 2 for resulting VBGF parameters).

Although the long life span calculated for *A. tuberculosa* in Costa Rica is not unreasonable, it must be pointed out that there were no individuals < 30mm in length used in the growth experiments. This means that the VBGF parameters obtained in this study do not necessarily describe the growth of juveniles. Exponential (Miller 2004) or linear (e.g. *A. senilis*) (Debenay *et al.* 1994) growth has been shown for juveniles of other tropical bivalves. It is therefore possible that juvenile *A. tuberculosa* reach maturity (roughly 27mm in length) (Ampie and Cruz 1989) at a somewhat different age than is suggested by the VBGF shown in Fig. 2.

While the above provides a good picture of *A. tuberculosa* growth in Costa Rica on the whole, it is still important to consider that growth in sedentary and semi-sedentary bivalves is greatly influenced by environmental and biological factors and is known to vary widely from population to population and individual to individual, even within the same species and population (Broom 1982a, Wolff 1987, Caddy 1989, Vakily 1992).

Different environmental conditions such as exposure time (height above chart datum), and water temperature and turbidity (Broom 1982a), salinity, (Ivanovici *et al.* 1981, Broom 1985) and contamination (Din and Ahamad 1995) have been shown to affect growth in *Anadara* spp. populations.

Additionally, a factor cited by Caddy (1989) and confirmed by Vakily (1992) for Mytilidae (mussels) and bivalves characterized by an "oval shell form," and Wolff (1994) for Pectinidae (scallops), is that geographic latitude is correlated with growth performance. This seems to hold true for *Anadara* spp. in that there is a positive correlation ($R^2= 0.8249$) between ϕ' values and latitude for the species shown in Fig. 4. If latitude is taken to correlate with water temperature, this pattern is consistent with the finding that growth in *A. granosa* is reduced when exposed to constantly higher temperatures (Broom 1982a).

Mortality and exploitation rate

Although a natural mortality rate of 0.14 year⁻¹ is low compared with other tropical bivalves (Broom 1983, Vakily 1992), there are several reasons to assume the accuracy of this rate. *A. tuberculosa* has a well protected adult

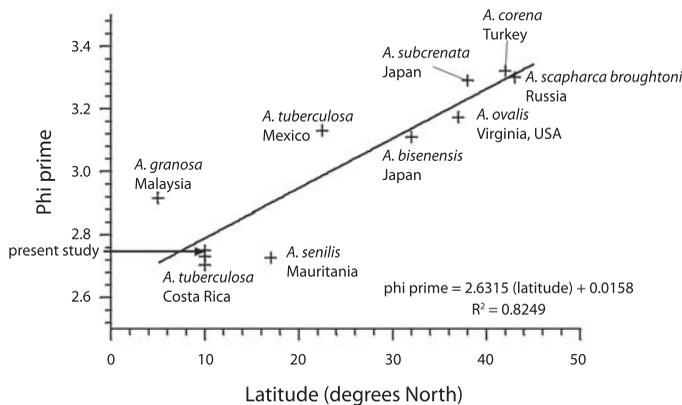


Fig. 4. Phi prime along a latitudinal gradient for *Anadara* spp.

habitat (among mangrove prop roots) and a thick shell. Also empty shells and dead individuals were rarely encountered in the mangrove areas during sampling. Lastly, there is a lack of evidence that *Anadara* spp. are preyed upon after reaching adult sizes in their natural environment (Broom 1982b, Villalobos and Báez 1983, Broom 1985, Koch 1995).

All three sites show exploitation rates above Gulland's (1984) recommended E_{10} cutoff for sustainable exploitation, with Purruja being most exploited and Rincón least, according to these criteria.

This heavy exploitation is confirmed by the size composition of *A. tuberculosa* in the study areas as compared with that in Sierpe-Térraba (Campos *et al.* 1990), and Baja California Sur, Mexico (Baquero 1980) (Table 3). In the aforementioned areas, average sizes as well as

maximum sizes of measured individuals was notably larger than that in the study sites. In B.C.S., Mexico, *A. tuberculosa* has a low market value and is thought to be underfished (Baquero 1980, MacKenzie 2001); and in the vast and remote Sierpe-Térraba, there is simply too much habitat for the few harvesters to overexploit. However in Colombia where Squires *et al.* (1975) report harvesting pressure similar to that in the Gulf of

Nicoya area of Costa Rica, the authors observed an average harvested length of *A. tuberculosa* on par with that of *A. tuberculosa* at Chomes in the present study. These findings further point to harvesting pressure as directly affecting the size composition of this species.

Other *Anadara* spp. populations found to be vulnerable to fishing pressure are *A. ovalis* occurring along the Atlantic coast of North America and *A. grandis*, which shares its range with *A. tuberculosa*. *A. ovalis* constitutes 1% of the commercial bivalve harvest along its coastline (Mcgraw *et al.* 2001) with landings over the past five years in Virginia ranging from 2.54 to 10.86 ton annually. (Anonymous 2004b) Even with this relatively small harvest in the global context, a study done in 1993 indicates that *A. ovalis* might already have been overexploited within only two years of the first commercial

TABLE 3
Length comparisons for *A. tuberculosa* in different locations

Location	Maximum length (mm)	Minimum length (mm)	Average length (mm)	Authority
Chomes, Costa Rica	71	11	43.8	Present study
Purruja, Costa Rica	67	32	48.6	Present study
Rincón, Costa Rica	67	29	46.7	Present study
Sierpe-Térraba (various locations), Costa Rica	69	34	51.5	(Campos <i>et al.</i> 1990)
Buenaventura, Colombia	110	34	43.0*	(Squires <i>et al.</i> 1975)
Magdalena and Almeja Bays, B.C.S. Mexico	118	16	63.2	(Baquero 1980)

harvesting (Mcgraw and Castagna 1995), in part because of its naturally low abundance and high market value (~\$ 17/kg) (Anonymous 2004b).

Additionally, anecdotal reports reveal that *A. grandis* is now considered "economically extinct" due to past overharvesting. Veteran cockle harvesters in Costa Rica report that 15-20 years ago they found and harvested many *A. grandis*, but now they almost never find one and there is no separate market for them anymore (occasionally when an individual is found, it's usually very small and sold along with the other two *Anadara* species). In Columbia, *A. grandis* is even considered an endangered species due to past harvesting pressure (Jameson *et al.* 2000).

Because of its slow growth, high exploitation, and the susceptibility other *Anadara* spp. have shown to overharvesting, it is clear that conservation measures should be implemented to prevent *A. tuberculosa* from becoming locally endangered in Costa Rica.

ACKNOWLEDGMENTS

The authors thank José A. Vargas-Zamora, Jenaro Acuña-González, Daisy Arroyo-Mora, and Margarita Silva-Benavides of CIMAR at the Universidad de Costa Rica for their generous help that enabled this study. Additionally, many thanks to the piangueros and piangueras in Chomes, Purruja and Rincón, including Mayra, Navidad, and Tatiana Ureña, Graciela Banquero and her family, Christina Camaño, Don Chepe and many others for their help and cooperation during the field work for this study. Lastly, thanks to Martha Liliana Fontalvo-Herazo for translation help on the manuscript. A. Stern-Pirlot's work was carried out for the ISATEC Master Program at the University of Bremen (Bremen, Germany).

RESUMEN

El presente estudio tuvo por objetivo la descripción de la dinámica poblacional y estado de la pesquería de la almeja del barro *Anadara tuberculosa* (conocida

localmente como piangua) en tres áreas de pesca a lo largo de la costa Pacífica de Costa Rica (Chomes, Purruja y Rincón), así como colocar los resultados en el contexto de la pesca de esta especie en Costa Rica y de otras especies de *Anadara* alrededor del mundo. El estudio está basado en la toma de muestras durante cinco meses, entre octubre 2003 y abril 2004, mediante medidas mensuales de la longitud y marcado de individuos. Los parámetros de crecimiento K y L_{∞} (0,14 y 63.15, respectivamente) según von Bertalanffy revelaron un desempeño de crecimiento ($\phi' = 2.75$) que está dentro del ámbito informado para esta familia de bivalvos, lo cual es indicador de la validez de esos valores. Los valores estimados de explotación oscilaron entre 0.62 (Rincón) y 0.76 (Purruja) y exceden los valores sostenibles en todos los sitios del estudio. La fuerte sobre-pesca en estos sitios, que se refleja también en los pequeños tamaños de las pianguas extraídas en comparación con otros sitios menos explotados en Costa Rica y otros países, se debe al tamaño relativamente pequeño de las poblaciones en cada sitio de pesca, así como su fácil acceso y alta importancia económica de la especie para los usuarios locales del recurso. Si no se aplican políticas de conservación, es probable que *A. tuberculosa* siga el camino hacia la extinción que lleva la especie hermana de mayor tamaño *A. grandis* (chucheca).

Palabras clave: *Anadara tuberculosa*, piangua, Costa Rica, Golfo Dulce, Golfo de Nicoya, pescarías, manglares, von Bertalanffy.

REFERENCES

- Ampie, C.L. & R.A. Cruz. 1989. Tamaño y madurez sexual de *Anadara tuberculosa* (Bivalvia: Arcidae) en Costa Rica. *Brenesia* 31: 21-24.
- Anonymous. 2004a. Average Monthly Rainfall 1950-2000 (Coto 47, Costa Rica). Instituto Meteorológico National, San José, Costa Rica.
- Anonymous. 2004b. Blood Ark landings 1998-2002. Virginia Marine Resources Commission, Virginia, USA.
- Baquiero, E. 1980. Population structure of the mangrove cockle, *Anadara tuberculosa* (Sowerby, 1833) from eight mangrove swamps in Magdalena and Almejas Bays, Baja California Sur, Mexico. *Proc. Natl. Shellfisheries Assoc.* 70: 201-206.
- Baqueiro Cárdenas, E. & D. Aldana-Aranda. 2000. A review of reproductive patterns of bivalve mollusks from Mexico. *Bull. Mar. Sci.* 66: 13-27.
- Bertalanffy, L.v. 1934. Untersuchungen über die Gesetzmäßigkeiten des Wachstums. 1. Allgemeine Grundlagen der Theorie. *Roux'Arch. Entwicklunsmech.Org.* 131: 613-653.

- Broom, M.J. 1982a. Analysis of the Growth of *Anadara granosa* (Bivalvia: Arcidae) in natural, artificially seeded and experimental populations. *Mar. Ecol. Prog. Ser.* 9: 69-79.
- Broom, M.J. 1982b. Size-selection, consumption rates and growth of the gastropods *Natica maculosa* (Lamarck) and *Thais carinifera* (Lamarck) preying on the bivalve, *Anadara granosa* (L.). *J. Exp. Mar. Biol. Ecol.* 56: 213-233.
- Broom, M.J. 1983. Mortality and production in natural, artificially-seeded and experimental populations of *Anadara granosa* (Bivalvia: Arcidae). *Oecologia* 58: 389-397.
- Broom, M.J. 1985. The Biology and Culture of Marine Bivalve Molluscs of the Genus *Anadara*. *ICLARM Studies and Reviews* 12: 1-37.
- Caddy, J.F. 1989. Recent Developments in Research and Management for Wild Stocks of Bivalves and Gastropods, p. 665-700. *In* J. F. Caddy (ed.). *Marine Invertebrate Fisheries: Their assessment and management*. John Wiley, Rome, Italy.
- Campos, J.A., M.L. Fournier & R. Soto. 1990. Estimación de la población de *Anadara tuberculosa* (Bivalvia: Arcidae) en Sierpe-Terraba, Costa Rica. *Rev. Biol. Trop.* 38: 477-480.
- de la Cruz, E. 1994. Morphometric Characterisation and Reproductive Biology of *Anadara tuberculosa* Populations from Different Mangrove Systems Located in the Nicoya Gulf, Costa Rica. Doctoral Thesis, URIFE Universitait, Belgium.
- Debenay, J.-P., D. Leung Tack, M. Ba & I. Sy. 1994. Environmental conditions, growth and production of *Anadara senilis* (Linnaeus, 1758) in a Senegal lagoon. *J. Molluscan Stud.* 60: 113-121.
- Din, Z.B. & A. Ahamad. 1995. Changes in the scope for growth of blood cockles (*Anadara granosa*) exposed to industrial discharge. *Mar. Pollut. Bull.* 31: 406-410.
- Froese, R. & C. Binohlan. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *J. Fish Biol.* 56: 758-773.
- Gabaev, D.D. & A.B. Olifirenko. 2001. Growth, stock, and production of *Scapharca broughtoni* in Peter the Great Bay, Sea of Japan. *Oceanology* 41: 403-412.
- Gayanilo, F.C.J. 2000. Fisheries Stock Assessment Tools II (FiSAT II). Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.
- Gayanilo, F.C.J., P. Sparre & D. Pauly. 1995. The FAO-ICLARM stock assessment tools (FiSAT). Users guide. FAO, Rome, Italy. 262 p.
- Gayanilo, F.C.J., P. Sparre & D. Pauly. 1997. FAO-ICLARM stock assessment tools (FiSAT). Reference Manuel. FAO, Rome, Italy, 126.
- Gulland, J.A. 1984. Advice on target fishing rates. *Fishbyte* 2: 8-11.
- Gulland, J.A. & S.J. Holt. 1959. Estimation of growth parameters for data at unequal time intervals. *J. Cons. CIEM* 25: 47-49.
- Hebbeln, D., D. Beese & J. Cortés. 1996. Morphology and sediment structures in Golfo Dulce, Costa Rica. *Rev. Biol. Trop.* 44: 1-10.
- Ivanovici, A.M., S.F. Rainer & V.A. Wadely. 1982. Free amino acids in three species of mollusc: responses to factors associated with reduced salinity. *Comp. Biochem. Physiol.* A 70A: 17-22.
- Jameson, S.C., V.F. Gallucci & J.A. Robleto. 2000. Nicaragua: Pacific coastal, p. 531-543. *In* C. Sheppard (ed.). *Seas at the millennium: An environmental evaluation*. Elsevier, Amsterdam, Holanda.
- Jiménez, J.A. 1999. Ambiente, distribución y características estructurales en los manglares del Pacífico de Centro América: contrastes climáticos, p. 380. *In* A. Yáñez-Arancibia & A. L. Lara-Domínguez (ed.). *Ecosistemas de Manglar en América Tropical*. Instituto de Ecología, A.C.UICN/URMA; NOAA/NMFS, Xalapa, Mexico; Silver Springs, MD USA; San José, Costa Rica.
- Koch, V. 1995. Zur Populationsbiologie und ökologischen Rolle der Mangrovenschnecke *Thais kioskiformis* im Golf von Nicoya, Costa Rica. Diplomarbeit. Universität Bremen, Bremen, Germany.
- Kress, N., S.L. Coto, C.L. Brenes, S. Brenner & G. Arroyo. 2002. Horizontal transport and seasonal distribution of nutrients, dissolved oxygen and chlorophyll-*a* in the Gulf of Nicoya, Costa Rica: a tropical estuary. *Cont. Shelf Res.* 22: 51-66.
- MacKenzie, C.L.J. 2001. The Fisheries for mangrove cockles, *Anadara* spp., from Mexico to Peru, with descriptions of their habitats and biology, the fishermen's lives, and the effects of shrimp farming. *Mar. Fish. Rev.* 63: 1-39.

- Madrigal, E.A. 1980. Algunos aspectos biológicos de *Anadara tuberculosa* ("piangua"). Ministerio de Agricultura y Ganadería, Departamento de Pesca y Caza Marítimas, San José, Costa Rica. 22 p.
- Mcgraw, K.A. & M. Castagna. 1995. Some observations on arkshell clams, *Noetia ponderosa*, and *Anadara ovalis*, and implications for fisheries management. J. Shellfish Res. 14: 272.
- Mcgraw, K.A., M. Castagna & L.L. Conquest. 2001. A study of the arkshell clams, *Noetia ponderosa* (Say 1822) and *Anadara ovalis* (Bruguiere 1789), in the oceanside lagoons and tidal creeks of Virginia. J. Shellfish Res. 20: 185-195.
- Miller, C.B. 2004. Biological Oceanography. Blackwell Science, Oxford, England, 402 p.
- Munro, J.L. 1982. Estimation of the parameters of the von Bertalanffy growth equation from recapture data at variable time intervals. J. Cons. CIEM 40: 199-200.
- Munro, J.L. & D. Pauly. 1983. A Simple Method for comparing the Growth of Fishes and Invertebrates. Fishbyte 1: 5-6.
- Pauly, D. 1983. Length-Converted Catch Curves: A Powerful Tool for Fisheries Research in the Tropics (Part I). Fishbyte 1: 9-13.
- Pauly, D. & G. Gaschütz. 1979. A simple method for fitting oscillating length growth data, with a program for pocket calculators. ICES C.M. G: 24: 26 p.
- Richards, R. 1965. Anoxic basins and fjords, p. 611-645. In J. P. Riley and G. Skirrow (ed.). Chemical Oceanography. Academic, London.
- Sahin, C., E. Düzgünes, C. Mutlu, M. Aydin & H. Emiral. 1999. Determination of the Growth Parameters of the *Anadara cornea* R. 1844 Population by the Bhattacharya Method in the Eastern Black Sea. Turkish J. Zool. 23: 99-105.
- Schmidt, S. M. Wolff & J.A. Vargas. 2002. Population ecology and fishery of *Cittarium pica* (Gastropoda: Trochidae) on the Caribbean coast of Costa Rica. Rev. Biol. Trop. 50: 1079-1090.
- Silva-Benavides, A.-M. & R. Bonilla-Carrion. 2001. Abundancia y morfometría de *Anadara tuberculosa* y *A. similis* (Mollusca: Bivalvia) en el Manglar de Purruja, Golfo Dulce, Costa Rica. Rev. Biol. Trop. 49: 315-320.
- Silva, A.M. & N.N. Carrillo. 2004. El manglar de Purruja, Golfito, Costa Rica: un modelo para su manejo. Rev. Biol. Trop. 52 (Suppl. 2): 195-201.
- Silva, A.M. & J. Acuña-González. 2006. Caracterización físico-química de dos estuarios en la bahía de Golfito, Golfo Dulce, Pacífico de Costa Rica. Rev. Biol. Trop. 54 (Suppl. 1): 241-256.
- Squires, H.J., M. Esteves, O. Barona & O. Mora. 1975. Mangrove cockles, *Anadara* spp. of the Pacific Coast of Colombia. Veliger 18: 57-68.
- Vakily, J.M. 1992. Determination and comparison of bivalve growth, with emphasis on Thailand and other Tropical Areas. ICLARM. Tech. Rep. 36: 125.
- Vargas, J.A. 1995. The Gulf of Nicoya estuary, Costa Rica: past, present, and future cooperative research. Helgol. Meeres. 49: 821-828.
- Vargas, J.A. & A. Mata. 2004. Where the Dry Forest Feeds the Sea: the Gulf of Nicoya estuary. p. 126-135. In G. W. Frankie, A. Mata & S. B. Vinson (ed.). Biodiversity Conservation in Costa Rica: Learning the Lessons in a Seasonal Dry Forest. University of California, Berkeley, California, USA.
- Vega, A.J. 1994. Estructura de población, rendimiento y épocas reproductivas de *Anadara* spp. (Bivalvia, Arcidae) en la Reserva Forestal Térraba-Sierpe, Puntarenas Costa Rica. Con recomendaciones para su manejo. Tesis de Maestría, Universidad de Costa Rica, San José, Costa Rica.
- Villalobos, C.R. & A.L. Báez. 1983. Tasa de crecimiento y mortalidad en *Anadara tuberculosa* (Bivalvia: Arcidae) bajo dos sistemas de cultivo en el Pacífico de Costa Rica. Rev. Lat. Acuic. Lima-Peru: 1-54.
- Voorhis, A.D., C.E. Epifanio, D. Maurer, A.I. Dittel & J.A. Vargas. 1993. The estuarine character of the Gulf of Nicoya, an embayment on the Pacific coast of Central America. Hydrobiologic. 99: 225-237.
- Wolff, M. 1987. Population dynamics of the Peruvian scallop *Argopecten purpuratus* during the El Niño phenomenon 1983. Can. J. Fish. Aquat. Sci. 44: 1684-1691.
- Wolff, M. 1994. The Scallop *Argopecten purpuratus*, p. 76-82. In M. Wolff (ed.). Population dynamics, life histories and management of selected invertebrates of the SE Pacific upwelling system. ZMT Center for Tropical Marine Ecology, Bremen, Germany.
- Wolff, M., V. Koch, J.B. Chavarría & J.A. Vargas. 1998. A trophic flow model of the Golfo de Nicoya, Costa Rica. Rev. Biol. Trop. 46 (Suppl. 6): 63-79.
- Wolff, M. 2006. Biomass flow structure and resource potential of two mangrove estuaries: Insights from

- comparative modelling in Costa Rica and Brazil. *Rev. Biol. Trop.* 54 (Suppl. 1): 69-86.
- Wolff, W.J., A. Gueye, A. Meijboom, T. Piersma & M.A. Sall. 1987. Distribution, biomass, recruitment and productivity of *Anadara senilis* (L.) (Mollusca: Bivalvia) on the Banc D'Arguin, Mauritania. *Neth. J. Sea Res.* 21: 1987.
- Wolff, M., H.J. Hartmann & V. Koch. 1996. A pilot trophic model for Golfo Dulce, a fjord-like tropical embayment, Costa Rica. *Rev. Biol. Trop.* 44 (Suppl. 3): 215-232.
- Wong, E., F. Antillón, E. Glenn & M.I. Gonzalez. 1997. Depuración microbiológica artesanal de la piangua, *Anadara tuberculosa* (Mollusca: Arcidae). *Rev. Biol. Trop.* 45: 1445-1452.