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Shell growth of the golden mussel, *Limnoperna fortunei* (Dunker, 1857) (Mytilidae), in the Río de la Plata, Argentina

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Abstract

The golden mussel, *Limnoperna fortunei*, is an invasive freshwater bivalve. Since its introduction to Argentina, it had caused damage to the native fauna as well as economic damage to industries of the region. Here, we describe the growth of *L. fortunei* in a natural temperate environment in Argentina. Age was estimated according to the modal progression method. The constants in the von Bertalanffy growth model were adjusted by an iterative algorithm. Three annual cohorts had similar growth rates. The estimated t_0 for each cohort showed a temporary displacement in relation to the spawning period.

Introduction

Limnoperna fortunei (Dunker, 1857) (golden mussel) is an invasive freshwater bivalve species, native to the rivers and streams of China and Southeast Asia. The first record in Argentina, and on the American continent in 1991, was from Bagliardi Beach, on the coast of the Río de la Plata. (Pastorino et al., 1993; Darrigran & Pastorino, 1995). Since then, a demographic explosion has occurred, with densities reaching 150 000 ind m^{-2} (Darrigran et al., 2000). This has caused environmental damage to the native fish and benthic fauna (Darrigran et al., 1998; Penchaszadeh et al., 2000), as well as large economic impacts (Darrigran & Ezcurra de Drago, 2000) similar to those caused by *Dreissena polymorfpha* (Pallas, 1771) in the northern hemisphere (Nalepa & Schloesser, 1993).

A few investigations of the biology of the golden mussel are available. Its life cycle and population dynamics in Asia were studied by Morton (1977, 1982) and Iwasaki & Uryu (1998). In the Neotropical region, Darrigran et al. (1999) studied the reproductive biology of a natural population from Río de la Plata, Argentina, between 1992 and 1994. Boltovskoy & Cataldo (1999) analyzed changes in the size-frequency structure of mussels colonizing experimental frames installed in the channel that diverts water used from nuclear plant in a Cuenca del Plata locality, Argentina.

The objective of this study was to describe the growth of *L. fortunei* in a natural temperate habitat in the Neotropical Region, to provide basic knowledge for the development of strategies to control the species.

Materials and methods

The sampling in this study was similar to that used for the description of this bivalve‘s reproductive cycle (Darrigran et al., 1999).

Samples were taken between March 1994 and March 1995 on the rocky coast of Bagliardi Beach (34° 52′ 28″ S; 57° 48′ 25″ W) during low tide. This locality has a temperate climate. Monthly mean air temperatures range between 7.8 °C (July) and 24.1 °C

Table 1. Parameters of each mode resulting from the polimodal decomposition for sampling date and assignment of relative age (t), in year parts starting from January 1°. M (mode), SD (standard deviation), and N (number of individuals)

t	Cohort 1			Cohort 2			Cohort 3		
	M	SD	N	M	SD	N	M	SD	N
0.16	3.50	0.87	88.26						
0.21	3.20	1.26	849.60						
0.23	3.47	0.89	627.37	0.50		105.00			
0.48	5.74	1.00	206.34	3.54	0.95	344.92			
0.74	8.14	2.13	965.38				3.03	0.18	404.70
0.81				7.56	1.42	470.00	3.17	1.05	207.00
0.90	10.41	2.00	758.44				5.56	1.00	84.91
1.16	11.78	1.79	383.13	11.78	1.79	383.13	6.92	0.55	27.00
1.21	12.25	2.90	677.80	12.25	2.90	677.80			
1.23	14.03	0.31	129.93	10.55	3.92	300.36	10.55	3.92	300.36
1.48	15.80	2.63	277.08				10.79	2.69	362.70
1.74	17.00	2.00	93.73						
1.81	17.50	2.72	160.00				12.50	2.35	333.00
1.90				15.86	2.06	129.21			
2.16	19.80	1.36	233.77	17.98	0.31	166.25	15.70	0.93	323.67
2.21				18.17	2.27	105.70			
2.23							17.13	2.14	315.98
2.48	20.95	0.29	17.32						
2.74	21.34	1.56	115.52	21.34	1.56	115.52	21.34	1.56	21.34
2.81	21.37	1.80	58.00	21.37	1.80	58.00	21.37	1.80	21.37
2.90	21.67	1.96	85.94	21.67	1.96	85.94	21.67	1.96	21.67
3.21	24.11	0.23	6.30	24.11	0.23	6.30	24.11	0.23	24.11
3.23	24.94	0.29	12.59	24.94	0.29	12.59	24.94	0.29	24.94

(January), and water temperatures between 14.0 °C (May) and 24.0 °C (February) (Guerrero et al., 1997).

Samples were taken by removing individuals from the substratum with a spatula. Rectangular section of variable dimensions were used as sampling units and expressed per 0.04 m^2. Specimens were preserved in 10% formaldehyde. Shell length was expressed in mm. For each sample a size-frequency distribution table was generated, with 1 mm class intervals. Distributions were decomposed into their unimodal components (Guerrero & Tablado, 1985). Age was assigned to each mode according to the modal progression analysis method (Pauly, 1984), assuming that each progression of mode represents a cohort. On this basis, annual cohorts were distinguished.

The von Bertalanffy growth model was used to estimate shell growth:

$$L_t = L_\infty \lfloor 1 - e^{k*\epsilon} \rfloor$$

where L_t is the mean length at t, $L\infty$ is the maximum asymptotic length, k is the growth coeficient, and ϵ is equal to $t - t_0$, relative age expressed in year. Growth parameters were estimated by the iterative method proposed by Pauly (1984).

The growth model was fitted using the data corresponding to each cohort**,** together with the modes of the larger size classes that could not be assigned to a specific cohort. Superimposing the modal sizes according to age, only one value of $L\infty$ was found for the population, starting from the estimated times of settlement (t_0). The remaining parameters were estimated using that value and weighed according to the number of specimens represented by each mode (Pauly, 1984).

Results

The multimodal decomposition by sample date and the age assignment according to the method of modal

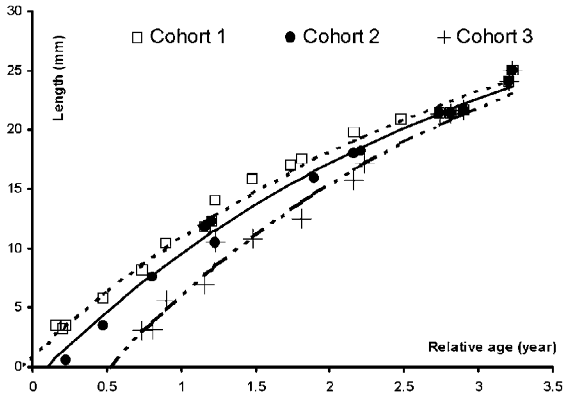

Figure 1. Adjustment of growth in the three cohorts of *Limnoperna fortunei*.

progression are presented in Table 1. Their representation on the time axis identifies three annual cohorts (C1, C2, C3). It was not possible to determine the cohorts for lengths larger than 22 mm (Fig. 1). Growth models were adjusted according to the version of seasonally oscillating length growth (VBSGF) and the generalized length growth (VBGF). The best result was obtained applying the VBGF weighted according to the number of specimens at each mode.

Figure 1 shows the growth of an average individual from settlement to maximum size for each cohort. Longevity is suggested to be 3.2 years. The model's growth parameters for each cohort are observed in Table 2. Growth rates of all cohorts were similar.

Each cohort presents a temporary displacement in relation to spawning (Fig. 2).

Discussion

Limnoperna fortunei is an invasive species that advances by 240 km y^{-1} from a temperate climate (Bagliardi Beach) (Darrigran & Escurra, 2000), toward the subtropics (El Pantanal) (Alice M. Takeda, com. pers.) in the Cuenca del Plata. This fact affects, among others, their reproduction (Darrigran et al., 1999) and growth (Smith et al., 1992).

Although three cohorts are apparent for the smallest size intervals, the largest intervals comprise a mixture of individuals of different cohorts. The estimated maximum length for the three cohorts is in agreement with growth patterns in bivalves described by Krommenhoek (1996).

Regarding growth model selection, Smit et al. (1992) in *Dreissena polymorpha* and Boltovskoy & Cataldo (1999) in *L. fortunei* found the best fit using the VBSGF. We consider that having a bigger number of samples distributed regularly in the year this probably had also been the model with the best fit, given the temperate climate of Bagliardi Beach.

The identification of more than one annual cohort agrees with observations of Darrigran et al. (1999) on the percentage of mature females during 1994. The estimated time of settlement for each cohort shows a displacement in relation to the time of gamete evacuation. This displacement is probably related with the period of the larval planktonic state. *L. fortunei* could spend 15–20 days as planktonic larvae (Choi & Kim, 1985; Escurra de Drago, pers. comm) similar to that of *Dreissena polymorpha* (Levinton, 1994). Figure 2 shows a peak of specimens of small size (between 0.5 and 3.5 mm) in March is coincident with an important spawning event in January. The presence of individuals of 0.5 mm in June could be due to the early spawning event from April to May. The absence of individuals smaller than 2 mm simultaneous with the great number of individuals larger than 6.5 mm length in September and November is due to a previous gonad rest period (Darrigran et al., 1999).

Boltovskoy & Cataldo (1999) determined a growth coefficient (k = 1) larger than that estimated here. They used data obtained in an artificial environment (nuclear power plant), showing environmental stability compared with the natural littoral population of the Río de la Plata estuary. Hoffmann et al. (2000) and Blanchard & Feder (2000) found statistically significant differences in growth rates of marine bivalves (k) as a consequence of variations in the environment of the geographical regions considered in their study.

In contrast to what was observed by Morton (1977), the golden mussel population in Bagliardi Beach appears to have continuous reproduction but with peaks of maturation related to temperature changes (Darrigran et al., 1999). The three cohorts of the present study are related with those changes (Fig. 2). Boltovskoy & Cataldo (1999) did not find peaks associated with thermal variations. This obser-

Table 2. Parameters of the growth curve and estimated settlement time, ($L\infty$ = 36 mm for all cohorts)

Cohort	t_0	k	R^2	settlement
C1	−0.071	0.3371	0.99	December 1993
C2	0.097	0.3409	0.98	February 1994
C3	0.513	0.3761	0.97	July 1994

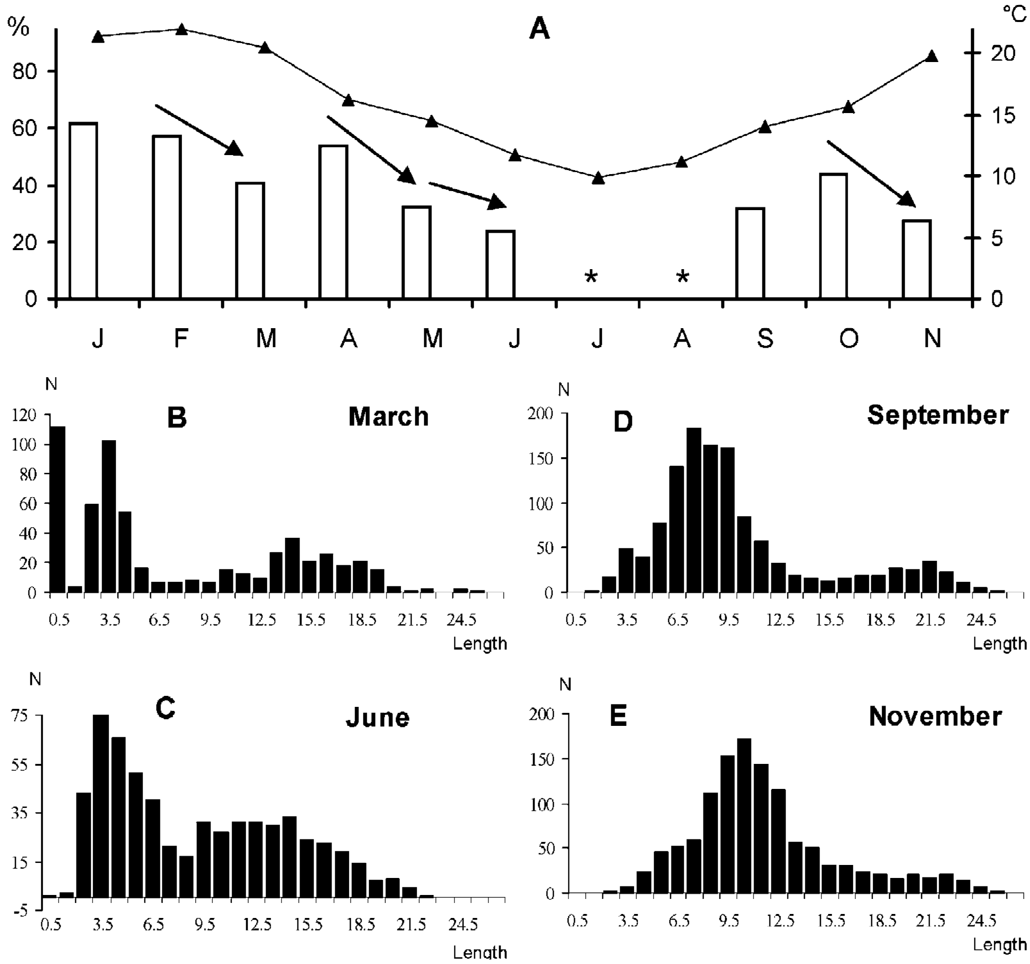

Figure 2. Comparison between gametic evacuation (Darrigran et al., 1999) and size frequency distribution of *Limnoperna fortunei* during 1995. *: without data. A: percentage of oocytes larger than 60 μm and mean air temperature (▲).The arrows indicate moments of gamete liberation. B–E: size frequency distribution (length in mm).

vation contrasts with the classic pattern of growth in bivalves (Vakily, 1992). Darrigran et al. (1999) made a gonad study of the local population while Boltoskoy & Cataldo (1999) infer continuous spawing on the basis of larvae in the environment. Differences between histological data and abundance of larvae in the plankton can be explained as resulting from drift of larvae from disjunct populations into the study area (Haag & Garton, 1992).

The longevity of the golden mussel is variable. Its life span in the natural environment of Bagliardi Beach, Argentina, was 3.2 years. Boltovskoy & Cataldo (1999) estimated it as 3 years in a Cuenca del Plata locality, Argentina. Iwasaki & Uriu (1998) suggested a longevity of 2 years in the Uji River, Japan, and from 4 to 5 years in Korea and over 10 years in Central China.

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References

Boltovskoy, D. & D. Cataldo, 1999. Population dynamics of *Limnoperna fortunei*, an invasive fouling mollusc, in the Lower Paraná River (Argentina). Biofouling 14: 255–263.

Blanchard, A. & H. M. Feder, 2000. Shell growth of *Mytilus trossulus* Gould, 1850, in Port Valdez, Alaska. Veliger 43: 34–42.

Choi, S. S. & J. S. Kim, 1985. Studies on the metamorphosis and the growth of larva in *Limnoperna fortunei*. Kor. J. Malacol. 1: 13–18.

Darrigran, G. & I. Escurra de Drago, 2000. Invasion of *Limnoperna fortunei* (Dunker, 1857) (Bivalvia: Mytilidae) in America. Nautilus 2: 69–74.

Darrigran, G. & G. Pastorino, 1995. The recent introduction of a freshwater Asiatic bivalve, *Limnoperna fortunei* (Mytilidae) into South America. Veliger 38: 171–175.

Darrigran, G., S. Martín, B. Gullo & L. Armendáriz, 1998. Macroinvertebrates associated with *Limnoperna fortunei* (Dunker, 1857) (Bivalvia, Mytilidae) in Río de la Plata, Argentina. Hydrobiologia 367: 223–230.

Darrigran, G., P. Penchaszadeh & M. C. Damborenea, 1999. The life cycle of *Limnoperna fortunei* (Dunker, 1857) (Bivalvia: Mytilidae) from a Neotropical temperate locality. J. Shellfish Res. 18: 361–365.

Darrigran, G., P. Penchaszadeh &.C. Damborenea, 2000. An invasion tale: *Limnoperna fortunei* (Dunker, 1857) (Mytilidae) in the Neotropics. Proc. 10th International Aquatic Nuisance Species and Zebra-Mussels Conference, Toronto, Canada. 2000: 219–224.

Guerrero, C. A. & A. Tablado, 1985. Programa básico para la descomposición de distribuciones polimodales. Bol. Asoc. Cienc. Nat. Litoral 5: 45–52.

Guerrero, R., C. Lasta, E. Acha, H. Mianzan & M. Framiñan, 1997. Atlas Hidrográfico del Río de la Plata. Comisión Administradora del Río de la Plata-Instituto Nacional de desarrollo Pesquero. Buenos Aires- Montevideo: 109 pp.

Haag, W. R. & D. W. Garton, 1992. Synchronous spawning in a recently established population of the zebra mussel, *Dreissena polymorpha*, in western Lake Erie, U.S.A. Hydrobiologia 234: 103–110.

Hoffmann, A., A. Bradbury & C. L. Goodwin. 2000. Modeling geoduck, *Panopea abrupta* (Conrad, 1849) population dynamics. I. Growth. J. Shellfish Res. 19: 57–62.

Iwasaki, K. & Y. Uriu. 1998. Life cycle of a freshwater mytilid mussel, *Limnoperna fortunei*, in Uji River, Kyoto. Venus 57: 105–113.

Krommenhoek, W., 1996. About growth patterns in gastropods and bivalves. Sea Shore 19: 114–116.

Levinton, J., 1994. The Zebra Mussel Invasion: a marine ecological perpective. Proc. of The Fourth International Zebra Mussel Conference, Madison, Wisconsin, U.S.A.: 525–542.

Morton, B., 1977. The populations dynamics of *Limnoperna fortunei* (Dunker 1857) (Bivalvia: Mytilacea) in Plover Cove reservoir, Hong Kong. Malacologia 16: 165–182.

Morton, B., 1982. The reproductive cycle in *Limnoperna fortunei* (Dunker, 1857) (Bivalvia: Mytilidae) fouling Hong Kong's raw water supply system. Oceanol. Limnol. Sin. 13: 312–325.

Nalepa, T. & W. Schloesser, 1993. Zebra Mussels: Biology, Imapcts, and Control. Lewis Publishers, Boca Raton: 508 pp.

Pastorino, G., G. Darrigran, S. Martín & L. Lunaschi, 1993. *Limnoperna fortunei* (Dunker, 1857) (Mytilidae), nuevo bivalvo invasor en aguas del Río de la Plata. Neotropica 39(101–102): 34.

Pauly, D., 1984. Fish Population in Tropical Waters: a Manual for Use with Programmable Calculator. ICLARM Studies and Reviews 8, Manila, Philippines: 325 p.

Penchaszadeh, P., G. Darrigran, C. Angulo, A. Averbuj, N. Brignoccoli, M. Brögger, A. Dogliotti & N. Pírez, 2000. Predation on the invasive freshwater mussel *Limnoperna fortunei* (Dunker, 1857) (Mytilidae) by the fish *Leporinus obtusidns* Valenciennes, 1846 (Anostomidae) in the Río de la Plata, Argentina. J. Shellfish Res. 19: 229–231.

Smit, H., A. bij de Vaate & A. Fioole, 1992. Shell growth of the zebra mussel (*Dreissena polymorpha* (Pallas)) in relation to selected physicochemical parameters in the Lower Rhine and some associated lakes. Arch. Hydrobiol. 124: 257–280.

Vakily, I. M., 1992. Determination and Comparison of Bivalve Growth, with Emphasis on Thailand and Other Tropical Areas. ICLARM Tech. Rep. 36, Manila, Philippines: 125 p.