Biological parameters and feeding behaviour of invasive whelk *Rapana venosa* Valenciennes, 1846 in the south–eastern Black Sea of Turkey

Hacer Saglam*, Ertug Düzgünès
Karadeniz Technical University, Faculty of Marine Science, Çamburnu 61530, Trabzon, Turkey

**Objective:** To determine length–weight relationships, growth type and feeding behavior of the benthic predator *Rapa whelk* at the coast of Camburnu, south–eastern Black Sea.

**Methods:** *Rapa whelk* was monthly collected by dredge sampling on the south–eastern Black Sea at 20 m depth. The relationships between morphometric parameters of *Rapa whelk* were described by linear and exponential models. The allometric growth of each variable relative to shell length (SL) was calculated from the function $Y=aSL^b$ or $\log Y=\log a+blogSL$. The functional regression $b$ values were tested by $t$-test at the 0.05 significance level if it was significantly different from isometric growth. The total time spent on feeding either on mussed tissue or live mussels was recorded for each individual under controlled conditions in laboratory.

**Results:** The length–weight relationships showed positive allometric growth and no inter–sex variability. Body size in the male population was significantly higher than in the individuals of the female. All characters in males and females showed a trend towards allometry rather than isometry. While the total time spent feeding increased with increasing prey size the total time that *Rapana venosa* spent feeding decreased with increasing *Rapa whelk* size. The total average feeding time needed by *Rapana whelks* was 160 min. But they took 310 min on live mussels in 27–28 °C in the laboratory conditions.

**Conclusions:** Length and weight relationships, growth type, total time spent feeding of this species were explained in details for this region. It would be useful to sustainable management in the south–eastern Black Sea of Turkey. The results about the feeding behaviour of this species will contribute to the understanding of the role of this species within the ecosystem.

**Keywords**

*Rapana venosa*, *Rapa whelk*, Length–weight relationships, Growth type, Feeding behaviour, Black Sea

---

**1. Introduction**

*Rapa whelk*, *Rapana venosa* Valenciennes, 1846, (*R. venosa*) is a predator native of Asian waters around Japan, China and Korea. *Rapa whelks* were first discovered out of its native range in Novorossiysk Bay in the Black Sea in the mid–1940s and spreaded throughout Adriatic[1], North America, Chesapeake Bay[2] and South America[3] in the recent decades. Ballast water transport of the planktonic larval stage between habitats is the most likely vector of introduction across traditional zoogeographic boundaries. The Asian *Rapa whelk* can tolerate wide ranges in salinity and temperature and combine with currents, has a high potential for spreading into invaded areas.

*Rapa whelk* reaches sexual maturity at 40 mm size[4]. This whelk is a predatory gastropod feeding mostly on bivalves and themselves can be preyed by lobsters, crabs, sea stars and various fishes, such as cod, dogfish and rays[5]. There are no major predators of invasive adult *R. venosa* in the Black Sea and the population has become very large and...
destructive to native marine life\(^6\). This predator has been responsible for the destruction of native oysters, scallops, and mussels populations\(^6\,7\).

Previously, there have been some studies on biological parameters (mean length and weight) and length-weight relationships of whelks obtained in the linear regression were significantly different from the isometric value (b=3), a t-test value, b=slope and SEb=standard error of the slope (b).

The 95% confidence interval, CI of b was computed using the equation:

\[
CI=b\pm(1.96\times SE)
\]

Where SE is the standard error of b. All the statistical analyses were considered at significance level of 5% (\(P<0.05\)).

2.2. Feeding behavior

Whelks (about 30 whelks) were maintained in fiberglass tanks (115 cm\(\times\)115 cm\(\times\)50 cm) supplied with continuously flowing seawater. Rapa whelks were allowed to acclimatise for 1–2 weeks and after that were placed in individual aquaria (30 cm\(\times\)30 cm\(\times\)30 cm), with water circulation and were fed mussel tissue or live mussels, *Mytilus galloprovincialis* (*M. galloprovincialis*). Feeding behaviour of whelks was observed during 24 h in each experiment.

In each experiment, each of the whelks was starved for 48 h and then presented a single meal of fresh mussel tissue, previously weighed to the nearest 0.01 g. The total time spent on feeding from the start of the feeding (from touch the shell of the prey with their foot) until end of feeding (to leave empty shell) on mussel tissue or live mussels was recorded for each individual. Effects of predator (*R. venosa*) size (71, 78 and 82 mm), prey (*M. galloprovincialis*) size (0.97, 1.35, 1.70 and 2.46 g), temperature (20 °C and 25 °C) and prey type (mussel tissue and live mussels) on the total time spent feeding were studied. At the end of the experiment shell length of each whelk was measured and the soft tissues of the animal were removed from the shell and weighted using a digital scale with a precision of 0.01 g.

3. Results

3.1. Biological parameters in Rapa whelks individuals

The parameters of each morphometric variable of females and males are presented in Table 1. The size of the Rapa whelk samples (1581 individuals) ranged from 13.5 to 95.8 mm shell length while the mean length, weight, shell free body weight and SW were about 52.85 mm, 27.73 g, 8.74 g and 20.10 g, respectively (Table 1). All characters measured were significantly larger in the females (n=340) than in the males (n=280) (\(P<0.05\); Table 1).

Table 1

| Parameters                  | Female      | Male        | Both        | Min–Max    | P     |
|----------------------------|-------------|-------------|-------------|------------|-------|
| Shell length (mm)           | 51.81±0.264 | 55.48±0.573 | 53.82±0.410 | 21.80–90.0 | <0.05 |
| Total weight (g)            | 25.48±0.945 | 31.74±0.942 | 28.91±0.711 | 1.41–122.8 | <0.05 |
| Body weight (g)             | 7.05±0.254  | 10.17±0.337 | 8.75±0.231  | 0.47–50.22 | <0.05 |
| Aperture length (mm)        | 39.27±1.047 | 43.32±0.734 | 40.98±0.500 | 28.40–57.20 | <0.05 |
| Shell width (mm)            | 36.36±0.553 | 39.80±0.457 | 38.18±0.393 | 8.80–57.00 | <0.05 |
| Shell weight (g)            | 18.44±0.723 | 21.57±0.641 | 20.16±0.504 | 0.30–74.91 | <0.05 |

Both: all individuals; Min–Max: minimum and maximum; P: statistical significance.
3.2. Length frequency distribution

The structure of the sampled population according to the length of females and males is presented in Figure 2. The shell length frequency distribution differed significantly between females and males ($t$-test, $P$<0.05).

3.3. Length weight relationships

Allometric analyses of weight–length relationship were done for both males and females to determine the growth type. Regression analysis showed that the slope (b) was significantly different from 3 ($t$-test, $P$<0.05) in both females and males, indicating a positive allometric growth pattern for both sexes ($b_{\text{female}}$=3.262, $b_{\text{male}}$=3.195, Table 2).

The parameters of the equation of each morphometric relationship were: $a$ and $b$, parameters of the equation; $R^2$, coefficient of determination; SE(b), standard error of b; M, male; F, female; Slope patterns are: $+$A, positive allometry; $-$A, negative allometry; I, isometry (Ho: $b$=1 for $Y$=a+$bX$, $b$=3 for $Y$=$aX^3$), SL: shell length, TW: total weight, BW: body weight, AL: aperture length, SW: shell weight, SW*: shell width.

3.4. Morphometric variables versus shell length

The parameters of the equation of each morphometric variable versus shell length of females and males are presented in Table 2. Shell weight and aperture length were linearly related to shell length. Weight, shell free body weight and shell weight were exponentially related to the shell length.

3.5. Feeding behaviour of Rapa whelk

According to laboratory observations, Rapa whelk opens the shell of the prey ($M. galloprovincialis$) by pulling apart the valves with the pressure exerted by Rapa whelk’s foot and by the excretions of digestive mucous. After inserting their proboscis between the valves of the bivalve, Rapa whelk eats all mussel tissue using the radular apparatus. There were mucous excretions on the shell of mussel after end of feeding.

The whelks used in the feeding trials ranged from 61 to 89 mm in shell length. The total time that Rapa whelk spent feeding decreased with increasing of Rapa whelk size. There was a significant difference in feeding time among experimental individuals of different sizes ($P$<0.05). The total time spent feeding also increased with increasing prey size ($P$<0.05), while the time from the starting of feeding to the meal was fully consumed decreased with the increasing temperature. Approximately 1 g mussel tissue was consumed in 18.5 min at 26 °C, and 70.6 min at 20 °C on average (Table 3, Figure 3).

### Table 2

| Parameters | Sex | Sex | $a$ | $b$ | $R^2$ | SE(b) | $t$-test | CI 95% for b | $P$ | Growth type |
|------------|-----|-----|-----|-----|-------|-------|-----------|--------------|----|-------------|
| TW=aSL$^b$ | F   | 0.00006 | 3.262 | 0.94 | 0.0482 | 67.659 | 3.168–3.356 | <0.05 | +A |
| BW=aSL$^b$ | M   | 0.00008 | 3.195 | 0.95 | 0.0423 | 75.605 | 3.112–3.278 | <0.05 | -A |
| SW=aSL$^b$ | F   | 0.00006 | 2.926 | 0.82 | 0.0825 | 35.469 | 2.764–3.088 | <0.05 | -A |
| AL=aLS$^b$ | M   | 0.00004 | 3.054 | 0.90 | 0.0567 | 53.858 | 2.943–3.165 | <0.05 | -A |
| SW=aLS$^b$ | F   | 0.00002 | 3.480 | 0.91 | 0.0560 | 53.511 | 3.353–3.607 | <0.05 | +A |
| AL=aL$^b$  | M   | 0.00004 | 3.242 | 0.92 | 0.1410 | 28.187 | 2.966–3.318 | <0.05 | I |
| SW=aL$^b$  | M   | -3.155  | 0.777 | 0.90 | 0.0242 | 32.107 | 0.730–0.824 | <0.05 | -A |

In females, total weight and shell weight revealed a positive allometric relationship (+A, $t$-test, $P$<0.05), while shell width and aperture length had a negative allometric relationship (−A, $t$-test, $P$<0.05). Body weight had an isometric relationship (I) with shell length ($P$>0.05) (Table 2).

In males, total weight had a +A relationship while the aperture length and shell width had a −A relationship ($t$-test, $P$<0.05). Body weight and shell weight increased isometrically with shell length ($P$>0.05, Table 2).

Regression analysis (comparison of slopes between sexes) revealed that three morphometric characters, (total weight, body weight and shell weight) were significantly different between females and males ($t$-test, $P$<0.05, Table 2).

### Table 3

| Variables | T ($^\circ$C) | N | L (mm) | PW (g) | Time (min) |
|-----------|--------------|---|--------|--------|------------|
| Prey size | 24           | 16 | 66.0±0.78 | 0.97±0.02 | 28.9±3.24 |
|            | 26           | 18 | 65.1±0.84 | 1.35±0.04 | 48.8±8.29 |
|            | 27           | 8  | 65.6±0.70 | 1.70±0.11 | 141.4±24.95 |
|            | 28           | 13 | 67.5±0.67 | 2.46±0.16 | 160.4±17.27 |
| Rapa whelk size | 12        | 7  | 70.0±1.15 | 0.97±0.04 | 50.8±4.76 |
|            | 15           | 17 | 78.2±0.82 | 0.96±0.02 | 26.4±1.85 |
|            | 15           | 15 | 81.7±0.89 | 0.96±0.01 | 18.4±1.72 |
| Prey type  | 28           | 13 | 67.5±0.67 | 2.46±0.16 | 160.4±17.27 |
|            | 27           | 11 | 71.7±0.58 | 14.08±0.09 | 309.6±27.81 |
| Temperature | 24           | 24 | 74.2±0.70 | 0.97±0.01 | 70.6±7.79 |
|            | 23           | 13 | 70.6±1.19 | 0.97±0.04 | 50.8±4.85 |
|            | 26           | 15 | 77.9±0.89 | 0.96±0.02 | 18.5±1.64 |

T: temperature; N: sample size; SL: shell length of Rapa whelk; PW: prey weight; Time: from start of feeding until the end; live mussels with shell.
The live mussels of (14.08±0.09) (n=11) g weight, having directly determined wet tissue weight of (2.34±0.19) g, was offered to Rapa whelk, (71.7±0.58) mm (n=11) shell length (Table 3). The whelk took about 310 min to consume live mussels, and 160.4 min to consume wet mussel tissue (2.46 g) at 27–28 °C. It spent more energy and time to open the shell of the live mussels.

4. Discussion

4.1. Biological parameters

Larger shell length ranges were reported for North Atlantic—USA (103–149 mm)[22], for Adriatic Sea (101–106 mm)[9], for Argentina—Uruguay (28–120 mm)[10] and for Korea (38.8–140.6 mm)[11] than the Black Sea specimens in Turkey (24–96.4 mm) [8], in Bulgaria (40–115 mm)[17], in Romania (35–80 mm)[18] and in the present study (14–96 mm). These differences may be caused by lack of sufficient food and space for high Rapa whelk population, overfishing and different fishing gears used to catch it.

The b values in both male and female of Rapa whelks in length and weight relationships showed positive allometric growth in the present study. This positive allometric relationship is also found in other studies in different areas like Adriatic (b=3.21)[9], the Rio de la Plata estuary, like Argentina—Uruguay (b=3.39)[10] and the west sea of Korea (b=3.21)[11]. But the other researchers reported a negative allometric growth for this species in Black Sea—Bulgaria, b=2.8[17], in Black Sea—Turkey, b=2.77[8], in Chesapeake bay, USA, b=2.43 and in Black Sea—Romania, b=2.56[19,20]. These differences between studies might have occurred in the different prey abundance, competition with native species and different levels of fishing exploitation (high in Black Sea, low in Atlantic), reflecting to the size structure of Rapa whelk catches.

4.2. Feeding Behaviour

Rapa whelks didn’t damage the shell of its prey in this study. In a similar way, it was reported that Rapa whelks produce their own toxins for paralyzing their prey (on bivalve species) and eating them with the aid of its soft proboscis without boring the prey shells[21]. Nevertheless, small Rapa whelks (<35 mm) feed by drilling through the bivalve shell, whereas large Rapa whelks (>35 mm) can attack and consume bivalves without leaving a drill–hole[22] or leaving slight predation marks on the edge of bivalve shells[10]. All of this variable feeding behaviours are reflecting the great plasticity of the Rapa whelks, which in turn can explain the great success of the species invading new areas.

In the present study, Rapa whelks (67.5 mm in shell length average) ate ~2.5 g Mytilus tissue in an average of 160 min (2.7 h). But Neptunea (70 mm in shell length) ate ~3 g Mytilus tissue in an average of about 32 h (from 19 h to 48 h) in 12–13 °C[23]. Rapa whelks consume the mussel faster than the Neptunea. Also Neptunea is a local gastropod against which Rapa whelk is competing. Invasive species are more severe competitors than local species. The whelk (Buccinum isotaakii) spent longer time in feeding on polychaetes (18.5 min) and sardine (18.2 min) preys while they spent little more than 1 min feeding on shrimp and squid for 1–day starvation period[23]. These results showed that the preys with shell like mussel were consumed faster than polychaetes and fish preys by whelks.

The estimated average food requirement for Rapa whelk was 1.2 g (Northern Adriatic), 0.68 g (Argentina), 0.2–0.3 g (South–eastern Black Sea) and 0.88 g (Uruguay) mussel tissue per day [12–14,24]. The approximately 1 g mussel tissue used in our experiments is higher than daily food requirement for Rapana.

In most of the locations and experiments mentioned, reflecting the high feeding plasticity of the species and also the different environmental conditions faced by this invasive species. In conclusion, the high success of this invasive species worldwide is clearly supported by its feeding behavior; therefore an appropriate management of the species in the region should include more population data and feeding behavior as presented here.

Conflict of interest statement

We declare that we have no conflict of interest.

Acknowledgements

This research was supported by Scientific Research Projects Coordination Unit of Karadeniz Technical University, Project No: 999.117.0015.

Comments

Background

The manuscript deals with the feeding behavior and the relationships between biological variables of an invasive species (R. venosa) in the Black Sea. New datas regarded
in this subject are needed for the understanding of the consequences of the worldwide invasion of *R. venosa*.

**Research frontiers**

The study is focused on the potential effects and capability of adaptation of an invasive species to new environments, particularly regarding feeding behavior of an exotic marine gastropod.

**Related reports**

There are many antecedents regarding the ability of this invasive species in dealing with local prey species and how they managed to predation upon distinct bivalves worldwide. All of them are properly cited in the bibliography of the manuscript.

**Innovations and breakthroughs**

The data is of great interest for the international scientific community worldwide.

**Applications**

Data presented in the manuscript can be of great interest for people in charge of management of natural resources, since this species exploit natural resources of commercial interest, like mussels, oysters and clam banks.

**Peer review**

The paper is of broad interest for scientists working in invasive species and fisheries in the region and worldwide. The methodology used in the manuscript is correct, presentation of results is appropriate.

**References**

[1] Cesari P, Pellizzato M. Settlement in the lagoon of Venice and the Adriatic distribution of *Rapana venosa* (Valenciennes) (Gastropoda, Thaïdidae). *Laveti Soc Ven Di Sci Nat* 1985; 10: 3–16.

[2] Harding JM, Mann R. Habitat and prey preferences of veined rapa whelks (*Rapana venosa*) in the Chesapeake Bay: direct and indirect trophic consequences. *J Shellfish Res* 1999; 18(1): 291.

[3] Pastorino G, Penchaszaideh PE, Schejter L, Brebec C. *Rapana venosa* (Valenciennes, 1846) (Mollusca: Muricidae): a new gastropod in south Atlantic waters. *J Shellfish Res* 2003; 19(2): 897–899.

[4] Sağlam H, Düzgünec E, Öğüt H. Reproductive ecology of the invasive whelk *Rapana venosa* Valenciennes, 1846, in the southeastern Black Sea (Gastropoda: Muricidae). *ICES J Mar Sci* 2009; 66(9): 1865–1867.

[5] Pearce JB, Thorson G. The feeding and reproductive biology of the red whelk, *Neptunea antiqua* (L.) (Gastropoda: Prosobranchia). *Ophelia* 1967; 4(2): 277–314.

[6] Zolotarev V. The Black Sea ecosystem changes related to the introduction of new mollusc species. *Mar Ecol* 1996; 17(1–3): 227–236.

[7] Drapkin EM. *Novii mollusc v cernom more*. *Prirodna* 1985; 3(8): 92–95.

[8] Düzgünec E, Ünsal F, Feyizoglu M, Sahin T. Stock assessment of sea snail (*Rapana thomassiana* gross 1861) in the Eastern Black Sea. *Trabzon, Turkey: Ministry of Food, Agricultural and Livestock, Central Fisheries Research Institute; 1992.*

[9] Savini D, Castellazzi M, Favuzzo M, Occhipinti–Ambrogi A. The alien mollusc *Rapana venosa* (Valenciennes, 1846; Gastropoda, Muricidae) in the Northern Adriatic Sea: population structure and shell morphology. *Chem Ecol* 2004; 20(Supp 1): S41–S42.

[10] Giberto DA, Brebec C, Schejter L, Schiariti A, Mianza’n HW, Acha EM. The invasive Rapa whelk *Rapana venosa* (Valenciennes 1846); status and potential ecological impacts in the Rio de la Plata estuary, Argentina–Uruguay. *J Shellfish Res* 2006; 25(3): 919–924.

[11] Choi JD, Ryu DK. Age and growth purple whelk, *Rapana venosa* (Gastropoda: Muricidae) in the West Sea of Korea. *Korean J Malacol* 2009; 25(3): 189–196.

[12] Seyhan K, Mazlum ER, Emiral H, Engin S, Demirhan S. Diet feeding periodicity, gastric emptying and estimated daily food consumption of whelk (*Rapana venosa*) in the south eastern Black Sea (Turkey) marine ecosystem. *Indian J Geo–Mar Sci* 2003; 32(3): 249–251.

[13] Savini D, Occhipinti–Ambrogi A. Consumption rates and prey preference of the invasive gastropod *Rapana venosa* in the Northern Adriatic Sea. *Helgol Mar Res* 2006; 60(2): 153–159.

[14] Giberto DA, Schiariti A, Brebec CS, Claudia S. Diet and daily consumption rates of *Rapana venosa* (Valenciennes, 1846) (Gastropoda: Muricidae) from the Rio de la plata (Argentina–Uruguay). *J Shellfish Res* 2011; 30(2): 349–358.

[15] Mumari C, Mistri M. Short–term hypoxia modulates *Rapana venosa* (Muricidae) prey preference in Adriatic lagoons. *J Exp Mar Biol Ecol* 2011; 407(2): 166–170.

[16] Sokal RR, Rohlf FJ. *Biometry: principles and practice of statistics in biological research*. 3rd ed. New York: W.H. Freeman & Co Ltd; 1995, p. 887.

[17] Prodanov K, Konstova T, Todorova V. Growth rate of *Rapana thomassiana* (Gastropoda) along Bulgarian Black Sea coast. In: Proceedings of the XXXIV Congress of CIESM; Malta. 1995.

[18] Bondarev VP. Dynamics of *Rapana venosa* (Valenciennes, 1846) (Gastropoda: Muricidae) population in the Black Sea. *Int J Mar Sci* 2014; doi: 10.5376/ijsm.2014.04.0003.

[19] Mann R, Harding JM, Westcott E. Occurrence of imposex and seasonal patterns of gametogenesis in the invading veined Rapa whelk *Rapana venosa* from Chesapeake Bay, USA. *Mar Ecol Prog Ser* 2006; 310: 129–138.

[20] Micu S, Kelemen B, Mustata G. Current distribution and shell morphotypes of *Rapana venosa* (Valenciennes, 1846) in the Agigea 4 m littoral. *Analele Stiintifice Ale Univ Al I Cuza Din Iasi Sectiunea I Biol Anim* 2008; 185–189.

[21] Chukhchin VD. *Ecology of the gastropod molluscs of the Black Sea*. Kiev: Naukova Dumka; 1984.

[22] Harding JM, Kingsley–Smith P, Savini D, Mann R. Comparison of predation signatures left by Atlantic oyster drills (*Urosalpinx cinerea* Say, Muricidae) and veined rapa whelks (*Rapana venosa* Valenciennes, 1846) in bivalve prey. *J Exp Mar Biol Ecol* 2007; 352(1): 1–11.

[23] Hano AS, Miranda RM, Fujinaga K, Nakao S. Feeding behavior and food consumption of Japanese whelk, *Buccinum isosotakii* (Neogastropoda: Buccinidae), *Fisheries Sci* 2005; 71(2): 342–349.

[24] Lanfranconi A, Brugnoli E, Muniz P. Preliminary estimates of consumption rates of *Rapana venosa* (Gastropoda, Muricidae); a new threat to mollusk biodiversity in the Rio de la Plata. *Aquat Invasions* 2013; 8(4): 437–442.