Marine Biology (2004) 145: 693–698
DOI 10.1007/s00227-004-1370-2

RESEARCH ARTICLE

E. Mutlu

Sexual dimorphisms in radula of *Conomurex persicus* (Gastropoda: Strombidae) in the Mediterranean Sea

Received: 17 June 2003 / Accepted: 25 March 2004 / Published online: 30 April 2004

Abstract Dentition characters of *Conomurex persicus* found along the Mediterranean coasts of Turkey were analyzed. For the analyses of radula, 289 individuals (34 adult males, 140 adult females and the remainder juveniles) were examined. Male and female individuals of the species had different numbers of radular cusps. The radula of the taenioglossate type was made up of two marginal teeth, one lateral and one central (rhachidian) tooth, each being delicate and with different numbers of cusps. The central and lateral teeth had seven cusps and five cusps, respectively, in both males and females. Outer and inner marginal teeth of males had two and one cusps, while those of females had five and six cusps, respectively. The female's radula is yellow-whitish. The male's radula is reddish dark brown.

Introduction

Conomurex persicus Swainson, 1821 was recorded first in the Mediterranean Sea (Iskenderun, southern Turkish coasts) in 1978 (Nicolay and Manoja 1983). *C. persicus* was at first restricted to the south coast of Arabia and part of the Persian Gulf (Abbott 1960; Moolenbeek and Dekker 1993). The species was then found on the coasts of Israel (Minetti 1983; Mienis 1984; Oliverio 1995) and Lebanon (Bogi and Khairallah 1987), on the southern coast of Turkey (Crucitti and Rotella 1991; Engl 1995) and on the coasts of Rhodes (Nicolay 1986) and Cyprus (Bazocchi 1985).

Communicated by O. Kinne, Oldendorf/Luhe

E. Mutlu
Institute of Marine Sciences,
Middle East Technical University,
POB 28, 33731 Erdemli, Mersin, Turkey
E-mail: mutlu@ims.metu.edu.tr
Fax: +90-324-5212327

Radular formula and the male's verge are basic keys in identification of species of the genus *Conomurex*, and the radula has been used as an important source of characters in gastropod systematics, both for taxonomy and for phylogenetic reconstruction. Appreciation of intra-specific variation in radular dentition can, in some cases, bring about an understanding of its cause. Previously, sexually dimorphic radulae have only convincingly been reported in neogastropods (*Nassa*, *Mancinella*, *Vexilla drupella* and *Pisania luctuosa* Tapparone-Canefri, 1880) (Arakawa 1958a, 1958b, 1964; Maes 1966; Cernohorsky 1971) and archaeogastropods (*Tricolia*) (Robertson 1971). A hypsogastropod (*Atlanta quoyii* Gray, 1850) has been reported to have sexually dimorphic taenioglossate radulae (Richter 1969). Ontogenetic variation of the radula has been described in *Conus* (Nybakken 1988, 1990; Nybakken and Perron 1988) and in trochoideans (Waren 1990), and intra-individual variation in *Peristernia* has been suggested to be a case of fluctuating asymmetry (Taylor and Lewis 1995). Extreme variation between individuals has been described in littorinids (Reid 1989, 1999) and lottiids (Simison and Lindberg 1999), and sexual dimorphism in dentition was found in muricids (Fujioka 1985a, 1985b, 1985c). The discovery of two adult radular types in a sacoglossan correlated with algal food plants suggests that radula morphology might be induced by diet (Bleakney 1990). Recently this has been demonstrated experimentally in *Lacuna* (Padilla 1998). Reid and Mak (1999) reported a study of the littorinid genus *Littoraria*, which suggests both ecophenotypic plasticity and phylogenetic constraint in radular form.

There have been only a few studies on the radular characters of *C. persicus* from the Mediterranean Sea and Persian Gulf; these did not note sexual dimorphism in the radulae (Abbott 1960; Nicolay and Manoja 1983; Wawra and Sattmann 1988; Moolenbeek and Dekker 1993).

The present paper shows sexual dimorphism and differences in morphological characters in the radulae of *C. persicus*.

Materials and methods

Samples for analyses of the radular characters of *Conomurex persicus* were collected on the Turkish Mediterranean coast, Mersin Bay (Fig. 1a), in February 2000, April 2002 and July 2002 (location 1), in 8 and 22 March 2003 (locations 2, 3, 6, 7), in April 2003 (locations 2, 3, 4, 5) and in June 2003 (location 1). The samples were collected with a standard dredge (60×15 cm mouth opening, 0.5×0.5 cm eye opening of net) deployed from on board the R.V. "Erdemli" for the first three sampling times and by diving on all other sampling occasions. Additionally, six individuals (two adult males and four adult females) were collected from a sandy coastal region (Yumurtalık; Fig. 1a) of Iskenderun Bay in April 2001 (Gucu et al. 2001). However, stomach analyses for diets of males and females were not performed. All adults occurred on sandy bottom (location 1), while juveniles inhabited rocks covered by red algae, *Jania rubens* Lamouroux, 1812, or sandy bottom covered by detritus in very shallow waters with depths of <2 m in the harbor (locations 2, 3, 4, 5, 6, 7; Fig. 1).

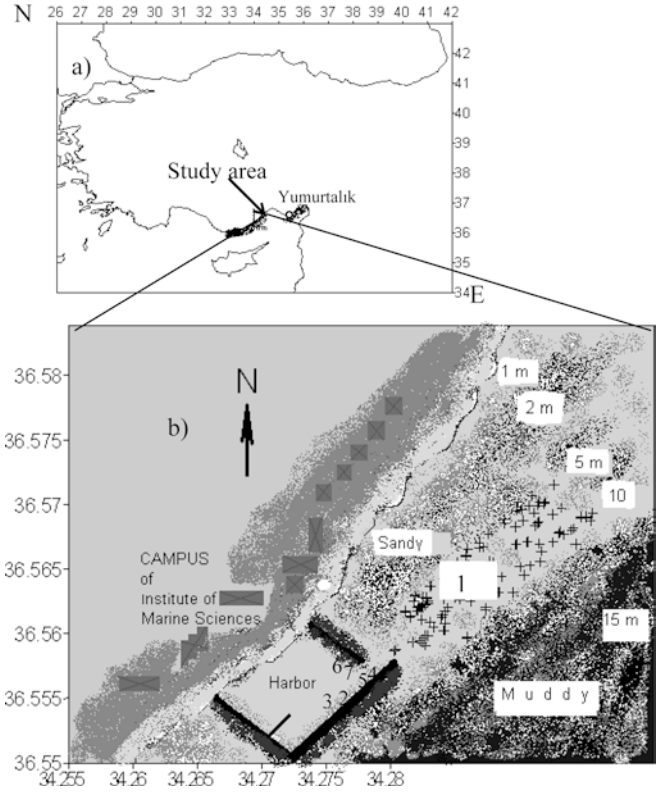

Fig. 1 a Locations where *Conomurex persicus* was observed along the coastal band (*black spots*) and at the study area where the dredge was deployed and **b** line stations (+) at 5 and 10 m depth contours and moles of the Institute of Marine Sciences' harbor. At location 1 (*1*, outside harbor) only adult individuals were found; locations 3, 7 and 5 (*3*, *7*, *5*, inside harbor) were of sandy bottom (bottom type 1); locations 2, 4 and 6 (*2*, *4*, *6*, inside harbor) were of rocks covered by a red algae, *Jania rubens* (bottom type 2)

Radulae of 289 adult individuals were examined, including 140 adult females, 34 adult males and the remainder juveniles (undefined sex). Sex of the adult individuals was determined according to presence/absence of the verge. Shell and verge lengths and proboscis (mouth) diameter of the individuals were measured. The numbers of cusps on each tooth were counted under a stereomicroscope.

For examinations in a scanning electron microscope (SEM, model JEOL JSM-840A), radulae were extracted from specimens preserved in alcohol (70% v/v). Radular ribbons were cleaned by soaking in a bleaching solution (1% w/v sodium hypochlolorite, 8% w/v sodium chloride) at room temperature (21°C) for up to 5 min, followed by gentle cleaning with fine needles and thorough rinsing in distilled water. Each radula was mounted damp on a thin layer of polyvinyl acetate glue on a glass coverslip. Specimens were coated with gold before examination with a SEM.

Results

Adult specimens were found between 4 and 12 m depth on sandy bottoms in the study area (Fig. 1b), whereas juveniles appeared only at <3 m depth and on rocks in the harbor (Fig. 1b). Shells of adult *Conomurex persicus* were thickened and toughened, and a U-shaped notch near the anterior end of the shell was well developed (Fig. 2a). Shells of subadults were thin, and the U-shaped notch was not completely developed (Fig. 2b).

The rhachidian tooth of the radula (taenioglossate type; Figs. 3a and 4a) was trapezoidal in shape, with seven obtuse cusps at the tip, lateral (with peg) and oblong subovate in outline and curved at the tip with five obtuse cusps the innermost of which is the largest. The radula had two sickle-shaped marginal teeth (inner and outer), with 1 cusp on the inner/2 cusps on the outer (1/1 rarely) in adult males (Fig. 3c) and 5/6 cusps in adult females (Fig. 4b).

Figure 5 shows changes in the total numbers of cusps on the marginal tooth, depending on verge and shell lengths of juveniles and of adult males and females. All juveniles had verges. As the verge and shell length of the juveniles increased, the total number of cusps decreased. The number decreased slightly from 11 (five cusps on the inner marginal tooth plus six cusps on the outer marginal tooth) to 7 when the verge length increased from 1 to 12 mm and the shell length from 1.5 to 4 cm. The number of cusps decreased abruptly to three when the verge length reached 14 mm. This length characterizes those individuals which have become adult males. Adult females were characterized by shell lengths >5 cm, the absence of a verge and the occurrence of 11 cusps on the marginal tooth. A significant correlation was found between the number of cusps and verge length (Spearman rank correlation, $r=-0.87$, $n=289$, $P=0.00$; Fig. 5). In Fig. 3, panels b (subadult male) and c (adult male)

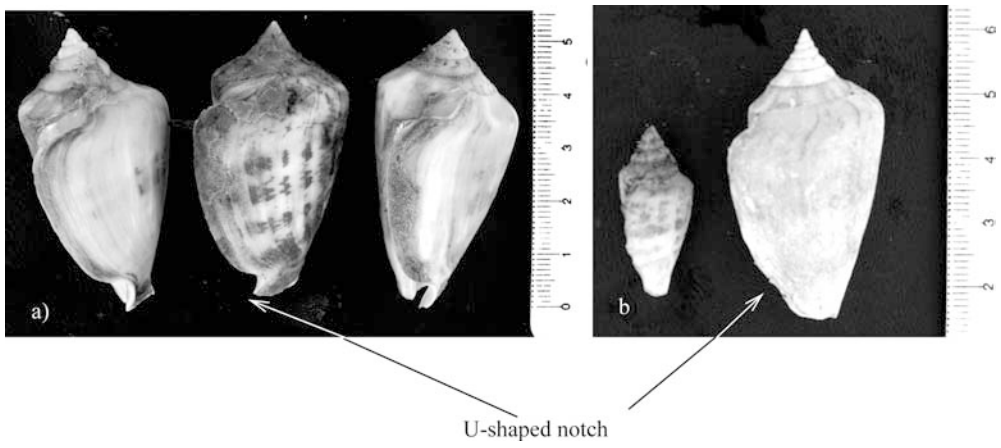

Fig. 2a, b *Conomurex persicus*. Shells of adult (**a**) and subadult (**b**) individuals

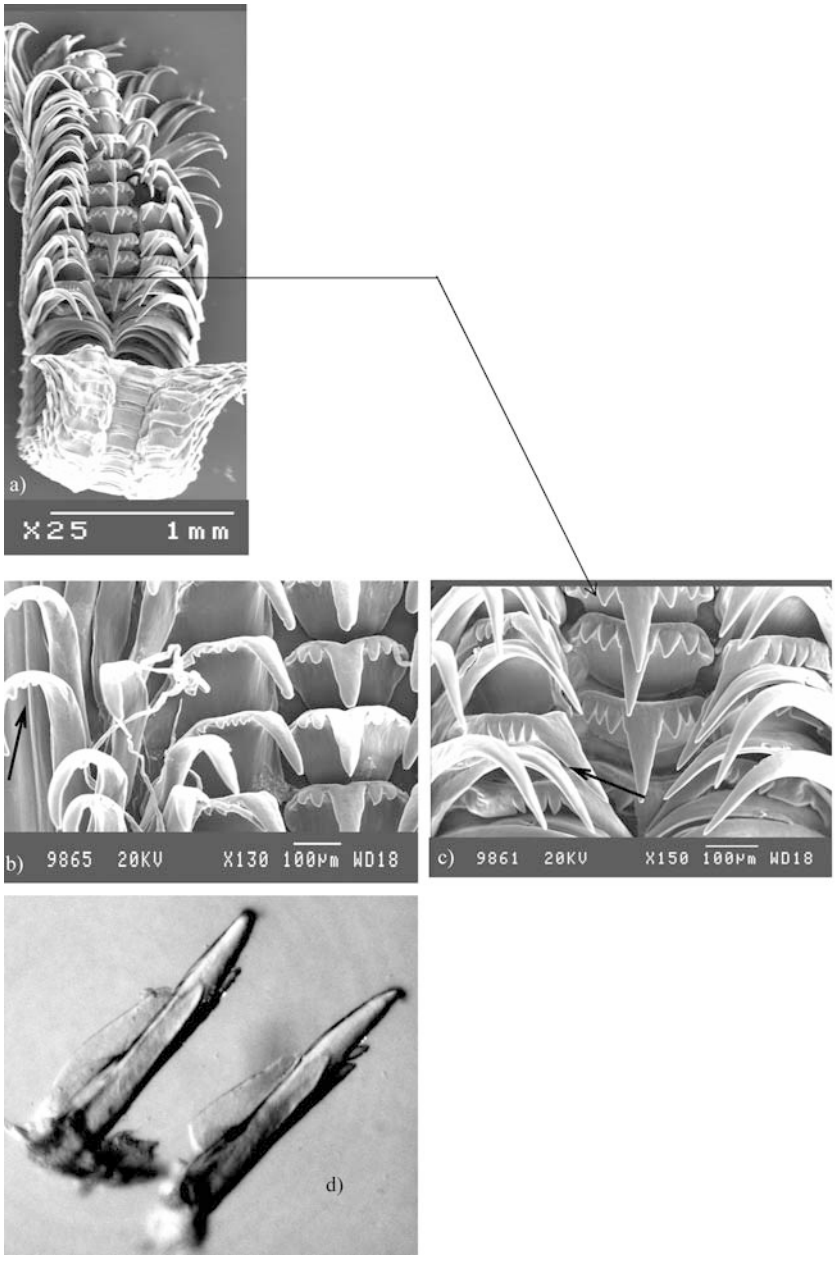

Fig. 3a–d *Conomurex persicus*. Radula of males. Radular ribbon (**a**), close-up view of the radula, with relatively large marginal cusps decreasing to three during the progress of dimorphism (**b**), close-up view of the sexually dimorphic radula (**c**) and close-up view of inner and outer marginal teeth, not coated with gold (**d**)

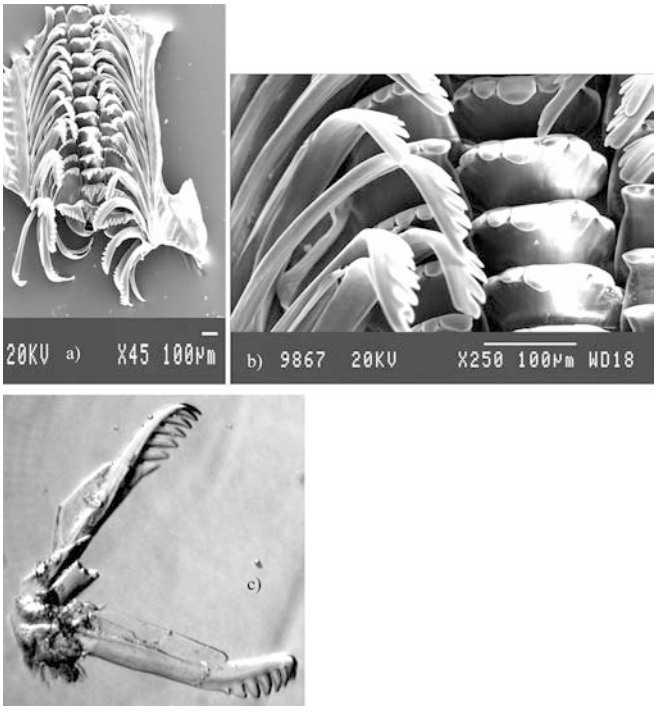

Fig. 4a–c *Conomurex persicus*. Radula of females. Radular ribbon (**a**), close-up view of the radula (**b**) and close-up view of inner and outer marginal teeth, not coated with gold (**c**)

show changes in the numbers of cusps on marginal teeth. However, the number of cusps of ten adult individuals with verge lengths varying between 12 and 22 mm (shell lengths of 5.0 and 5.5 cm), which were collected from bottom type 1 in April 2002, remained 11. The same phenomenon was observed in four individuals from sandy bottom (location 7) sampled on 22 March 2003.

The color of the female's radula is yellow-whitish. The color of the male's radula is dark brown. The radular formula of the female differs from that of the male in morphometry. The middle cusp of the rhachidian teeth is thinner and longer in the male (113 µm long) than in the female (40 µm long). The marginal tooth of the female was flattened, whereas it was a tube-like cylinder shape in the male. Ratios of the longest cusps to those on each of the lateral and central teeth were greater in males than in females (Table 1). The radular ribbon of the male is wider than that of the female, as a function of proboscis diameter (Fig. 6).

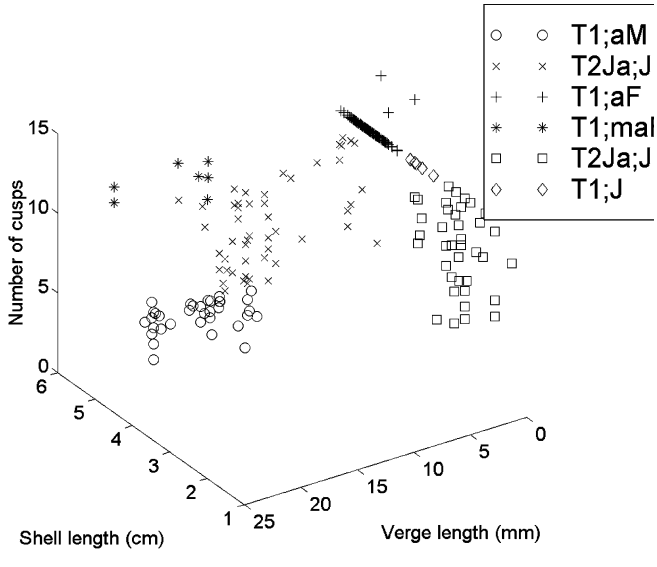

Fig. 5 *Conomurex persicus*. Total number of cusps on the marginal teeth as a function of shell and verge lengths (see Fig. 1b for locations of the bottom types) [*T1;aM* bottom type 1, adult males; *T2Ja;J* bottom type 2, juveniles on rocks covered by *Jania rubens* (*cross symbol* from locations 4 and 7; *square symbol* from location 2); *T1;aF* bottom type 1, adult females; *T1;maF* bottom type 1, masculinized females; *T1;J* bottom type 1, juveniles]

Discussion

Up to now, sexually dimorphic radulae have not been reported for a stromboid species (Abbott 1960; Nicolay and Manoja 1983; Wawra and Sattmann 1988; Moolenbeek and Dekker 1993; Moolenbeek, personal communication), but sexual differences in the sizes of stromboid shells have already been demonstrated (Abbott 1960).

The occurrence of sexual dimorphisms in the radula of *Conomurex persicus* could be related to habitat, feeding type and/or diet. The radula may be phenotypically plastic, and the appropriate morphology may be induced by substrate or diet (Reid and Mak 1999). *Strombus decorus* lives in colonies on coral sand, sponge and weedy bottoms, whereas *C. persicus* lives on sandy bottoms and in coral sand of Indo-Pacific regions (Abbott 1960). Adult *C. persicus* inhabited slightly gravelly, sandy bottoms and feed on seaweeds and detritus (non-corallivorous). Juvenile forms (shell length < 2 cm) live in colonies on small rocks covered by algae in the study area. Reid and Mak (1999) suggested that the inducible plasticity may explained the nearly perfect correlation between radula and substrate, as Padilla (1998) suggested that a plastic radular morphology may be adaptive for a species in a spatio-temporally variable environment, in which individuals regularly experience shifts of habitat during their lifetime. Juveniles of *C. persicus* were observed in two different habitats: (1) rocks covered mostly by the red algal order Corallinales (*Jania rubens*; bottom type 2, location 2) and (2) sand bottom with detritus (bottom type 1, location 3) in the harbor (Fig. 1).

Microscopic examination of the radula showed that marginal teeth become sexually dimorphic as follows. The number of cusps on the marginal teeth of small juveniles was 11. As the verge and shell became longer, the number of cusps was reduced as the size of most cusps decreased and one tooth became pointed. Ultimately, the tooth appeared to be a hook-like structure. Nybakken (1990) showed that the radular teeth of some

Table 1 *Conomurex persicus*. Individual ratios of cusp lengths of each tooth of adult male and female radula (ratios were calculated in reference to the shortest cusp on each tooth)

Central teeth (from center to edge)		Lateral teeth (from inner side to edge)		Inner marginal teeth (from bottom to top)		Outer marginal teeth (from bottom to top)	
Males	Females	Males	Females	Males	Females	Males	Females
3.5	1.7	3.7	1.8	1.0	1.0	1.0	1.0
1.2	1.0	1.0	1.3		1.2	1.2	1.0
1.0	1.0	1.0	1.0		1.2		1.3
1.0	0.7	1.0	1.0		1.2		1.3
		1.0	1.0		1.2		1.3

species of the carnivorous genus *Conus* also underwent a morphological change during their ontogeny. The type of change differs according to the different feeding types, but the initial juvenile tooth appears similar in all. The change from juvenile to adult tooth appeared to occur quickly, and presumably resulted from the initiation of the activity of the superior epithelial tissue. Ontogenetic change in morphology would occur in those species in which there was a marked change in diet between juveniles and adults, but not in those in which prey remained unaltered. Robertson (1971) showed that the radular dimorphism of *Hiloa* could be due to the males feeding on calcareous algae while the females feed on *Padina* and on epiphytes and detritus. The juveniles of *C. persicus* from rocky shores had pointed marginal teeth, whereas those from sandy bottoms with detritus had bluntly rounded marginal teeth, as Reid and Mak (1999) suggested for *Littorina subrotundata*. In her description of the intra-specific radular dimorphism of *Lacuna*, Padilla (1998) remarked only on the difference in shape of the cusps, classifying them as blunt or pointed, and suggesting that the former were more effective for scraping epiphytes from eelgrass blades, while the latter were more suited to excavation of algal thallus.

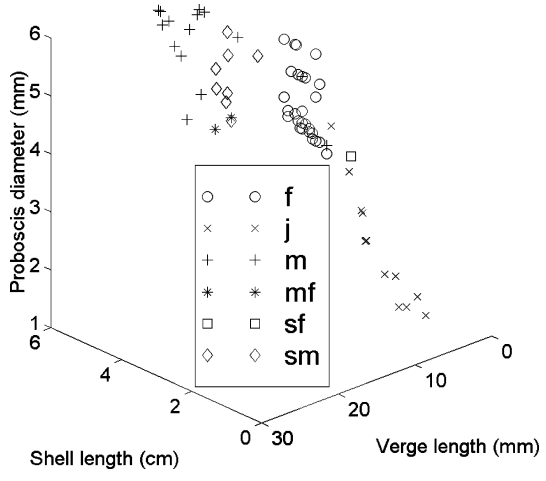

Fig. 6 *Conomurex persicus*. Sex dependent proboscis diameter change as a function of verge and shell lengths (*f* adult female; *j* juvenile; *m* adult male; *mf* masculinized female; *sf* subadult female; *sm* subadult male)

Sexually dimorphic marginal teeth were, however, not observed in ten individuals of the total number (43 females and 22 males) collected on bottom type 1 in April 2002, even though they had long verges (12–22 mm). Inherently, the sex ratio of *C. persicus* was 60–57% females to 40–43% males in the study area (Mutlu and Ergev, unpublished data). Total number of cusps on their marginal tooth remained unchanged at 11. Thus, these ten individuals could be masculinized females. Reed (1993a, 1995) showed sexual trimorphism in the shell (weight/length/width) and the occurrence of masculinized females for *Strombus pugilis* Linnaeus, 1758 and *Conomurex luhuanus* Linnaeus, 1758 at Shirahama, Japan. Masculinized females were indistinguishable from normal females, except for the presence of a small, deformed verge, which microscopically resembled that of a normal male (Reed 1993b). The occurrence of a masculinized female could have been proved by microscopic examination of the gonad tissue to detect any undeveloped, inactive spermatogenic tissue, which would have shown that these individuals were androgynous males, as Reed (1993a) suggested.

In conclusion, sexually dimorphic radulae have not previously been shown in other strombiid species, and the occurrences in *C. persicus* from the Mediterranean Sea may be altogether exceptional. It is interesting to note that the marginal teeth of adult male *C. persicus* all had fewer cusps than those of corresponding females. Not only size of the radular ribbon, but also color of the radula differed between adult males and females. Dimorphism needs to be considered in all future radular studies of strombiid gastropods in their habitats worldwide.

Acknowledgements The present study was carried out within the framework of the project "Seasonal distribution of macrobenthos in coastal region (Erdemli-Kumkuyu) of Levantine Basin in Mediterranean Sea" (project code: YDABCAG-100Y015) funded by the Scientific and Technical Research Council of Turkey (TUBITAK). I thank also Drs. R.G. Moolenbeek and F. Bingel for their suggestions and comments during the present study. I am indebted to Mr. A. Oner for taking photographs of the radulae.

References

Abbott TR (1960) The genus *Strombus* in the Indo-Pacific. Indo-Pac Mollusca 1:33–146

Arakawa KY (1958a) On the remarkable sexual dimorphisms of radulae of *Drupella*. Venus 19:206–214
Arakawa KY (1958b) Some notes on radula of *Purpura echinulata* Lamarck. Venus 20:69–75
Arakawa KY (1964) A study on the radulae of the Japanese Muricidae. Venus 22:355–364
Bazocchi P (1985) Prima segnalazione di *Strombus* (*Conomurex*) *decorus raybaudii* Nicolay and Romagna-Manoja, 1983 per l'Isola di Cipro. Boll Malacol 21:64
Bleakney JS (1990) Indirect evidence of a morphological response in the radula of *Placida dentritica* (Alder and Hancock, 1843) (Opisthobranchia: Ascogglossa/Sacoglossa) to different alga prey. Veliger 33:111–115
Bogi C, Khairallah NH (1987) Nota su alcuni molluschi de provenienza Indo-Pacifica raccolti nella baia di Jounieh (Libano), contributo I. Not CISMA 10:54–60
Cernohorsky WO (1971) Indo-Pacific Pisaniinae (Mollusca: Gastropoda) and related buccinid genera. Rec Auckl Inst Mus 8:137–167
Crucitti P, Rotella G (1991) Una popolazione di *Strombus* (*Conomurex*) *decorus* del Golfo di Iskenderun (Turchia sud-orientale): biometria e osservazioni ecologiche. Boll Malacol 26:211–218
Engl W (1995) Specie prevalentemente lessepsiane attestate lungo lessepsiane attestate lungo le coste turche. Boll Malacol 31:43–50
Fujioka Y (1985a) Formation and replacement of radular teeth in muricid gastropods. Zool Sci 2:1009
Fujioka Y (1985b) Seasonal aberrant radular formation in *Thais bronni* (Dunker) and *Thais clavigera* (Kuster) (Gastropoda, Muricidae). J Exp Mar Biol Ecol 90:43–54
Fujioka Y (1985c) Sytematic evaluation of radular characters in Thaidinae (Gastropoda: Muricidae). J Sci Hiroshima Univ 1:235–287
Gucu AC, Uysal Z, Mutlu E, Kideys A, Tugrul S, Bingel F (2001) Identification of marine fauna and flora of a petroleum terminal in the Iskenderun Bay—spring survey. Middle East Technical University, Institute of Marine Sciences, Erdemli, Icel
Maes VO (1966) Sexual dimorphism in the radula of the muricid genus *Nassa*. Nautilus 79:73–80
Mienis HK (1984) *Strombus decorus persicus* found in Israel. Hawaii Shell News 32:4
Minetti R (1983) Non-stop spreading of Mediterranean *Strombus*. Conchiglie (Milan)l 176/177:29
Moolenbeek RG, Dekker H (1993) On the identity of *Strombus decorus* and *Strombus persicus* with the description of *Strombus decorus masirensis* n. spp. and a note on *Strombus fasciatus*. Vita Mar 42:3–10
Nicolay K (1986) Sempre piu diffuso il strombo del Mediterraneo. Conchiglie (Milan) 202/203:29
Nicolay K, Manoja ER (1983) *Strombus* (*Conomurex*) *decorus raybaudii* n. spp. Conchiglie (Milan) 176/177:17–18
Nybakken J (1988) Possible ontogenetic change in the radula of *Conus patricius* of the eastern Pacific. Veliger 31:222–225
Nybakken J (1990) Ontogenetic change in the *Conus* radula, its form distribution among the radular types, and significance in systematics and ecology. Malacologia 32:35–54
Nybakken J, Perron F (1988) Ontogenetic change in the radula of *Conus magus* (Gastropoda). Mar Biol 98:239–242
Oliverio M (1995) The status of the living Mediterranean *Strombus*, or: what is a lessepsian migrant? Not CISMA 16:35–40
Padilla D (1998) Inducible phenotypic plasticity of the radula in *Lacuna* (Gastropoda: Littorinidae). Veliger 41:201–204
Reed SE (1993a) Size differences between sexes (including masculinized females) in *Strombus pugilis* (Mesogastropoda, Strombidae). J Shellfish Res 12:77–79
Reed SE (1993b) Gonadal comparison of masculinized females and androgynous males to normal males and females in *Strombus* (Mesogastropoda, Strombidae). J Shellfish Res 12:71–75
Reed SE (1995) Sexual trimorphism in *Strombus luhuanus* Linne, 1758 (Mollusca, Gastropoda) at Shirahama, Japan. J Shellfish Res 14:159–160
Reid DG (1989) The comparative morphology, phylogeny and evolution of the gastropod familiy Littorinidae. Philos Trans R Soc Lond Ser B 324:1–110
Reid DG (1999) The genus *Littoraria* Griffith & Pidgeon, 1834 (Gastropoda: Littorinidae) in the tropical eastern Pacific. Veliger 42:21–53
Reid DG, Mak Ym (1999) Indirect evidence for ecophenotypic plasticity in radular dentition of *Littoraria* species (Gastropoda: Littorinidae). J Molluscan Stud 65:355–370
Richter G (1969) Heteropoden und Heteropodenlarven im Oberflachen-Plankton des Golfs von Neapel. Mar Ecol 36:346–400
Robertson R (1971) Sexually dimorphic archaeogastropods and radulae. Annual report for 1970. American MalacologicaI Union, New York, pp 75–78
Simison WB, Lindberg DR (1999) Morphological and molecular resolution of a putative cryptic species complex: a study of *Notoacmea fascicularis* (Menke, 1851) (Patellogastropoda: Gastropoda). J Molluscan Stud 65:99–109
Taylor JD, Lewis A (1995) Diet and radular morphology of *Peristernia* and *Latirolagena* (Gastropoda: Fasciolaridae) from Indo-Pacific coral reefs. J Nat Hist 29:1143–1154
Waren A (1990) Ontogenetic changes in the trochoidean (Archaeogastropoda) radula, with some phylogenetic interpretation. Zool Scr 19:179–187
Wawra VE, Sattmann H (1988) Bemerkungen zur Radula von *Strombus decorus* (Röding, 1978) (Gastropoda: Prosobronchia) aus dem Mittelmeer. Ann Naturhist Mus Wien B 90:357–360