

# THE LITTORAL TROCHOIDEA (MOLLUSCA: GASTROPODA) OF THE AZORES

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*Abstract* A revision of the Azorean littoral Trochoidea is conducted and a description of the shell, animal and radula is provided. The endemic *Calliostoma lividum* (Dautzenberg 1927), originally proposed as a variety of *C. conulus*, is herein elevated to specific status and re-described. Of the remaining littoral trochid species reported from the Azores, two are dubious records, two are endemic (*Jujubinus pseudogravinae* and *Gibbula delgadensis*) and one has a wide geographical distribution in the North Atlantic (*Gibbula magus*). A note on the Pleistocene fossil record from Santa Maria is added and the dispersal abilities of the littoral trochids are commented.

## INTRODUCTION

The taxonomy of the Azorean Trochoidea has been surrounded by frequent confusion and species from this superfamily were often misidentified as similar European species by the 19<sup>th</sup> century authors (MacAndrew, 1856; Drouët, 1858; Jeffreys, 1883; Watson, 1886; Dautzenberg, 1889). Besides Dautzenberg's (1927) paper (where the Azorean *Calliostoma* is first described) and Nordsieck's (1973, 1982), where two endemic species (*Jujubinus pseudogravinae* and *Gibbula delgadensis*) were described, no other taxonomic studies dealt in detail with the shallow-water Trochoidea of the Azores.

The main objective of this work is to update the systematics of the group in the Azores. In the process, a compilation of the published information is carried out, with particular attention to the synonymy and the distribution of species by island. In addition, the Pleistocene fossil record from Santa Maria Island is referred.

## MATERIALS AND METHODS

A bibliographic revision of the shallow-water species (intertidal to a depth of about 50 m) was made. Only primary sources were selected; references not directly related to the Azores, but where species are mentioned for the archipelago based only on bibliography, were not included (e.g.:

Cretella, 1992). The synonymy and the distribution of species by island were also annotated.

Relevant occurrences will be cited from the two Pleistocene marine fossiliferous outcrops from Santa Maria (Prainha, located on the south coast of the island, near Praia Formosa beach, about 5 km east of Vila do Porto, with fossiliferous layers extending for 800 m along the seashore at the present height of +2 to +4 m, and Lagoinhas, located on the north coast at +7.4 m above present sea-level and with a longitudinal extension of less than 100 m) (for a review see Ávila *et al.*, 2002; Ávila, 2005; Ávila *et al.*, 2008, 2009).

More than 840 lots from the collection of the Department of Biology of the University of the Azores (DBUA), corresponding to about 600 dives in all islands, were examined and the trochids identified. Selected juveniles were photographed and their protoconchs measured to assess their modes of development. Unless stated otherwise, all the material herein referred to is deposited at the DBUA collection. Type material from the Dautzenberg Collection, deposited at the Royal Belgian Institute of Natural Sciences (Brussels, Belgium) was also examined. Type material from the Nordsieck collection, deposited at the Senckenberg Museum (Frankfurt, Germany) as well as information regarding these specimens was provided by Ronald Janssen. The trochids from the Nordsieck collection were photographed by Eike Neubert (Senckenberg Museum, Frankfurt).

Trochidae and Calliostomatidae are held as separate families in the Trochoidea, following Bouchet *et al.* (2005).

#### ABBREVIATIONS USED IN TEXT

DBUA	marine molluscs reference collection of the Department of Biology of the University of the Azores.
DC-RBINS	Dautzenberg Collection (Royal Belgian Institute of Natural Sciences, Brussels, Belgium).
NCSM	Nordsieck collection (Senckenberg Museum, Frankfurt, Germany).
DOP/ML	molluscs reference collection of the Department of Oceanography and Fisheries, University of the Azores, Horta.
ImagDOP	image bank of the Department of Oceanography and Fisheries, University of the Azores, Horta.
DBUA-F	fossil reference collection of the Department of Biology of the University of the Azores (Ponta Delgada, São Miguel Island, Azores).

#### RESULTS

Six littoral species of Trochoidea are reported from the Azores, of which two are dubious records (*Clanculus bertheloti* and *Gibbula umbilicalis*), three are endemic (*Jujubinus pseudogravinae*, *Gibbula delgadensis* and *Calliostoma lividum*, the last herein raised to specific rank) and one has a wide distribution in the North Atlantic (*Gibbula magus*).

#### ANNOTATED TAXONOMIC LIST

Clade Vetigastropoda Salvini-Plawén 1980  
 Superfamily Trochoidea Rafinesque 1815  
 Family Trochidae Rafinesque 1815  
 Genus *Clanculus* Montfort 1810

#### *Clanculus bertheloti* (d'Orbigny 1840)

##### References for the Azores

*Clanculus bertheloti* (d'Orbigny 1834). MacAndrew, 1856: 121, 147 (Azores, at shore); Nordsieck, 1982: 44 (Azores).

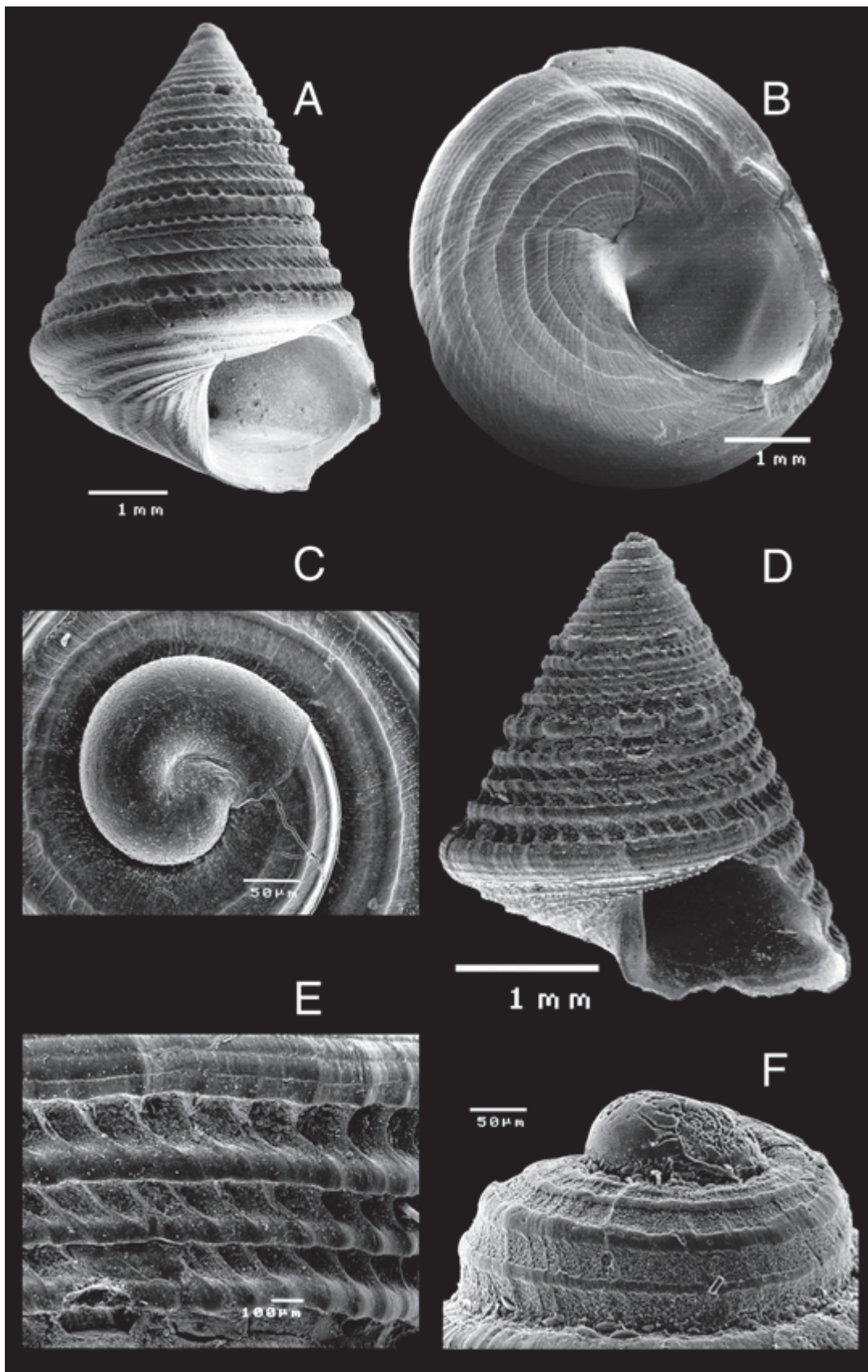
*Remarks* The record of *Clanculus bertheloti* stems only from a name in the list of MacAndrew (1857) [Report for 1856, published in 1857], repeated in Nordsieck's book. It has not been found again despite extensive collecting and it is unlikely that there are *Clanculus* in the Azores. This record should be deleted from Azores' checklists. The genus *Clanculus* was not found in the outcrops that were examined at Santa Maria Island (Ávila *et al.*, 2002; Ávila, 2005).

#### Genus *Jujubinus* Monterosato 1884

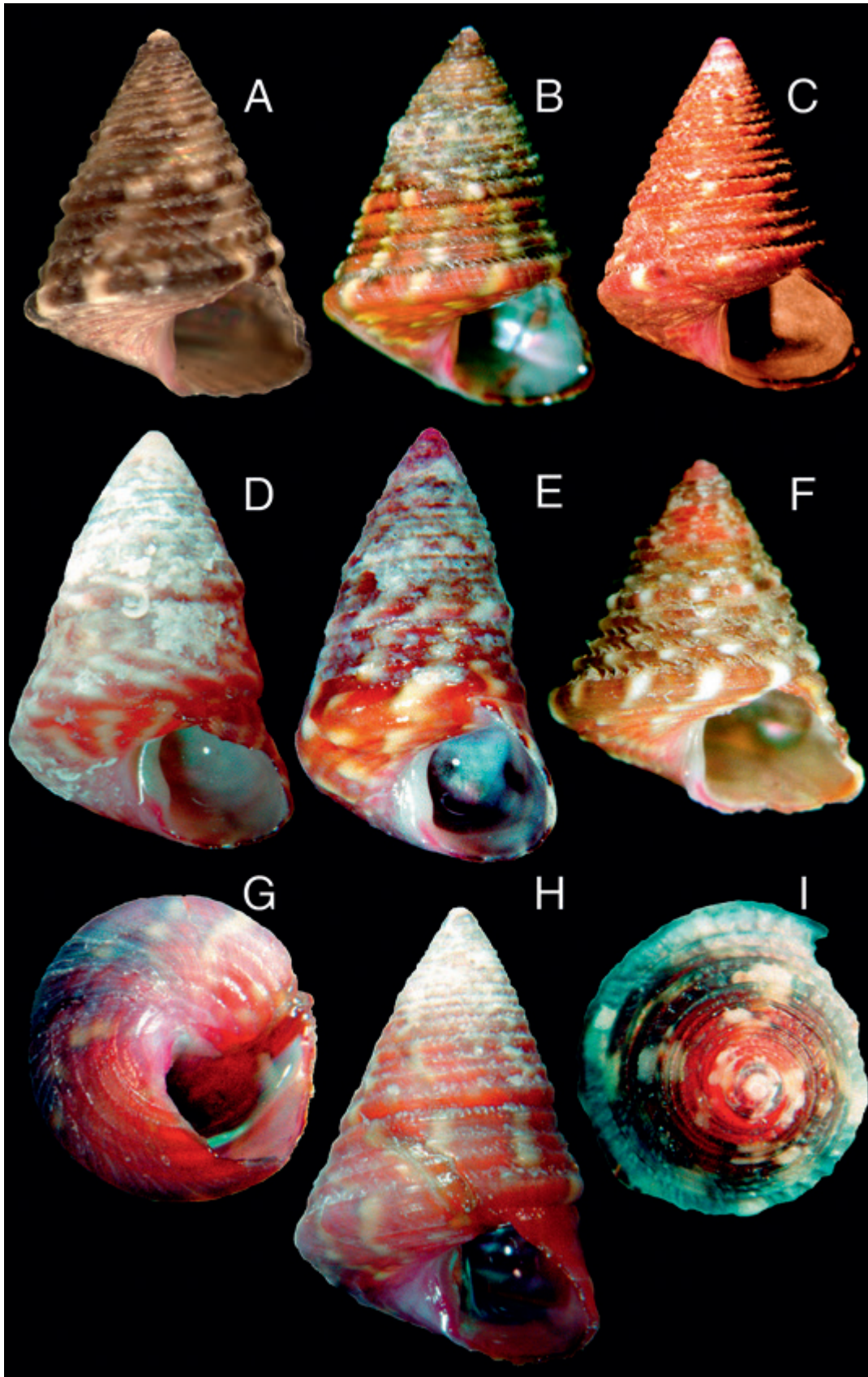
#### *Jujubinus pseudogravinae* Nordsieck 1973 (Figs 1, 2)

##### References for the Azores

*Trochus striatus* Linnaeus 1758. MacAndrew, 1856: 120 (Azores) (misidentification).  
*Calliostoma (Jujubinus) exasperatus* (Linnaeus 1766). MacAndrew, 1856: 147 (Azores) (misidentification).  
*Trochus erythroleucos* Gmelin 1791. (Drouët, 1858: 29) (São Miguel) (misidentification).  
*Trochus (Ziziphinus) exasperatus* (Pennant 1777). Watson, 1886: 696 (off Faial, 80 to 150 m, Stn. 75, "Challenger", 1873) (misidentification).  
*Calliostoma (Jujubinus) exasperatus* (Pennant 1777). Dautzenberg, 1889: 63 (Faial, Horta, 15 to 20 m, Stn. 103, "Hirondelle", 1887); Nobre, 1924: 82 (São Miguel, Ponta Delgada; Pico, Cais do Pico; Faial, Horta); Nobre, 1930: 59 (São Miguel, Ponta Delgada; Pico, Cais do Pico; Faial, Horta) (misidentification).  
*Jujubinus pseudogravinae* Nordsieck 1973. Nordsieck, 1973: 12, fig. 18 (São Miguel, Ponta Delgada); Nordsieck, 1982: 43–44 (Azores, Ponta Delgada); Azevedo & Gofas, 1990: 84 (Flores, Santa Cruz); Ávila & Azevedo, 1996: 106 (Pico); Ávila *et al.*, 2000: 143 (São Miguel); Ávila, 2003: 15, 17 (São Miguel); Ávila, Cardigos & Santos, 2004: 77 (Banco D. João de Castro); Martins, 2004: 50 (Ilhéu de Vila Franca do Campo).  
*Jujubinus exasperatus* (Pennant 1777). Azevedo, 1990: 59 (Pico, Lajes do Pico); Azevedo, 1991: 20 (São Miguel, Caloura and Ribeirinha); Morton *et al.*, 1998: 55 (São Miguel, Caloura) (misidentification).  
*Calliostoma exasperatus* (Montagu 1803). Morton & Britton, 1995: 70 (São Miguel, off Vila Franca do Campo) (misidentification).



**Figure 1** *Jujubinus pseudogravinae*. **A** Apertural view. **B** Bottom view. **A, B:** DBUA 574-2/119-1. **C** Top view of protoconch: DBUA 574-1/125-2. **D** Apertural view. **E** Detail of the microsculpture of the teleoconch. **F** Lateral view of protoconch. **D-F:** DBUA 574-3/123-2.



**Figure 2** *Jujubinus pseudogravinae*. **A** Apertural view: NCSM. **B** Apertural view: DBUA 574-1/125-2. **C** Apertural view: DBUA 574-2/119-1. **D** Apertural view: DBUA 238. **E** Apertural view: DBUA 486. **F** Apertural view: DBUA 574-3/123-2. **G** Bottom view. **H** Apertural view. **G**, **H**: DBUA 563. **I** Top view: DBUA 682.

*Jujubinus exasperatus* f. *tricolor* (Pennant 1777). Ávila & Azevedo, 1996: 106 (Pico) (misidentification).

*Jujubinus* sp. Ávila, 2000a: 14 (São Miguel).

*Jujubinus pseudogravinea* (sic!) Nordsieck 1973. Segers, 2002: 87 (Azores).

*Type material* 82 syntypes at the Senckenberg Museum from the type locality (Ponta Delgada, no date, no collector and not yet catalogued) (Ronald Janssen, *in litt.*).

*Type locality* Ponta Delgada, São Miguel Island (Azores).

*Material examined* Banco D. João de Castro (DBUA 814); Faial (DBUA 371–372, 378, 387–388, 390, 394–396, 400, 405, 407–408, 415, 418, 421–422, 424, 429, 432, 438, 441); Flores (DBUA 193, 195, 233, 238, 240, 249, 267, 274, 278, 281, 550, 553, 555–558, 560–561, 563, 565, 567–570, 575, 576–577, 579); Formigas (DBUA 330, 340–341, 345, 350, 353, 355, 362); Graciosa (DBUA 103); Pico (DBUA 460, 462, 481, 486, 499, 660–662, 667, 669–672, 677, 726); São Miguel (DO 63; DBUA 125, 168, 173, 176, 605, 608–609, 614, 616, 624, 626, 655–657, 673, 675, 683, 686–689, 692, 695–696, 698, 703/C, 707/G, 709, 715, 719, 721, 728, 730–733, 735, 739, 742, 746, 748–749, 754–755, 762, 764, 766–769, 771–774, 776–777, 779–781, 783, 785, 787–791).

*Description* (Figs 1, 2) Shell: solid, opaque, high-conic in adult specimens (with more than 5 teleoconch whorls), usually 8 to 10 mm, rarely up to 13 mm high, diameter 5.5 to 6.5 mm; less conic in juveniles. Height/diameter ratios between 1.33–1.37 (juveniles) and 1.50–1.70 (adults). Teleoconch with 7 whorls, the two uppermost convex, with 4 spiral cords, the second usually more pronounced; following whorls flat, separated by a projecting broad carina, granulated on the first whorls and covered with numerous, very small ridgelets, which are especially apparent on the body whorl; above the carina there are 3 conspicuous ridges, not granulated and narrower than the furrows, first ridge largest, located immediately below the suture and covered with very small, secondary ridgelets more evident on the last whorls, the other two irregularly spaced; the ridges and the carina are stronger on the first whorls, becoming less pronounced and rounder on the body whorl; sometimes small, second-

ary ridgelets can be seen between the principal ones on the last whorls; the furrows between the ridges are covered with very sharp, prosocline lamellae, more visible on the first whorls. Base convex, with six flat concentric ridges, narrower than the furrows; numerous growth lines evident on the base, crossing both the ridges and the intervals between them. Umbilicus closed even in juveniles, covered with a white callus. Aperture quadrangular; columella white, tinged with lilac on the border, with one prominent, rounded denticle on the lower part; interior of the aperture nacreous. Colour of the shell variable, brown, orange-brown and olive-green with white or yellow flammules, often arranged in irregular, longitudinal bands across the whorls, sometimes bordered with brown; bright red or near black specimens can also occur; colour of base similar to that of the whorls, with some of the stripes projecting towards it. Operculum multispiral, very thin, almost transparent and yellowish. Protoconch 200 to 205 µm in diameter, about 1.0 whorls, eroded in most adults.

Animal reddish-brown, variously mottled mostly on the posterior half of the foot which is papillose; papillae whitish, well developed in a furrow on the posterior dorsal tip; sole of foot superficially bipartite longitudinally, dark yellow to white (Fig. 7A, B). Head dark-brown, becoming lighter towards the neck. Cephalic tentacles dark-brown dorsally, whitish ventrally, long, tapering, villose, the pedunculate black eyes protruding from their outer base; two yellowish, frilled cephalic lappets descend from the inner base of the tentacles and curve inwards at the middle of the snout; neck lobes wide, undulated, dorsally greyish-green with whitish spots near their light yellow edge, ventrally brownish-red, continuing posteriorly as the epipodium; three pairs of villose, purplish-brown epipodial tentacles arise from the base of the epipodium, the two posterior pairs encircled by a white patch; a brown-capped papillar sense organ protrudes from the posterior base of each tentacle.

Radula rhipidoglossan ( $\infty + 5 + 1 + 5 + \infty$ ) $\times 46$  (Fig. 8A, B). Central tooth with base very wide, lower quarter quadrangular, inflating abruptly and assuming a roughly conical shape tapering into a double neck, the anterior portion very narrow and attaching to the underneath of the crown, the posterior part flaring out and bending to continue anteriorly and form the crown; crown

small, with sharp, triangular mesocone and serrated edges with about 5 small, sharp cusps. Lateral teeth becoming gradually larger, the basis flaring outwards, with outer margins rounded; crown of the first two laterals slightly larger than that of the central tooth, elongated, with mesocone triangular, sharp, endocone and ectocone serrated, with three to four subequal cusps; third and fourth laterals with wider crowns, elongated and blunt mesocone, endocone and ectocone with two to three small cusps; fifth lateral with large, quadrangular crown, mesocone rounded, endocone with one small, sharp cusp, ectocone with two cusps, the anterior strongest. Marginal teeth very narrow, the first five with long, narrow, tricuspidate crown, mesocone long and rounded, endocone and ectocone sharp; from the sixth marginal outwards the crown decreases gradually and the endocone and ectocone become first bicuspid, then tricuspid and eventually pectinate.

*Ecology* Specimens were found usually associated with algae in shallow waters. This is the most abundant of the trochoidean species in the Azores. The empty shells of this species are commonly occupied by specimens of the intertidal hermit crab *Clibanarius erythropus* (Latreille 1818) (Botelho & Costa, 2000).

*Bathymetric range* Intertidal down to 80 m, more common between 3 and 25 m.

*Geographic distribution* Endemic to the Azores, occurring on all islands (Ávila, 2005).

*Fossil record* Reported from Prainha outcrop (Pleistocene) (Santa Maria Island) (DBUA-F 2, 59, 65, 134, 139, 140) (Ávila *et al.*, 2002; Ávila, 2005).

*DNA Sequences* Partial sequences of the 16S rRNA mitochondrial gene (Genbank EF469254) and of the internal transcribed spacer 1 (ITS1) (Genbank EF469258).

*Remarks* Nordsieck (1973: 12) described *Jujubinus pseudogravinae* based on specimens collected at São Miguel Island (Ponta Delgada). His fig. 18 represents a juvenile. Although the description corresponds to the juveniles present at the DBUA collection, the figure is of poor

quality and, in view of the taxonomic confusion surrounding this species, Nordsieck's description was in need of reviewing. There are 82 syntypes at the Senckenberg Museum from the type locality (Ponta Delgada, no date, no collector and not yet catalogued) (Ronald Janssen, *in litt.*), and a holotype was not designated in the original publication; therefore, a more detailed description of this species is provided. A total of 969 specimens from the type locality (Ponta Delgada) were examined as well as specimens from other localities of São Miguel, and several hundred specimens collected at other islands (Faial, Flores, Formigas, Graciosa and Pico).

Despite its name, *Jujubinus pseudogravinae* is by no means a close relative of *Jujubinus gravinae* (Dautzenberg 1881). As correctly pointed by Cretella (1992) it belongs to the species group around *J. exasperatus* (Pennant 1777) (and was misidentified as this species by many authors). *Jujubinus pseudogravinae* can be distinguished by a series of shell characters, summarised in Table 1. Compared to *J. pseudogravinae*, the shell of *J. gravinae* is smaller, the early whorls have a unique, undulated and thick suprasutural cord which later loses the undulations, and has a lower height/diameter ratio. The intermediate spiral ridges are always smooth and only very fine growth lines are visible in the furrows between them. One of the spiral ridges of the first teleoconch whorl is very prominent giving the apex a scalar appearance. *Jujubinus exasperatus* has a conical shell, with a very prominent carina and a flat base. Both the carina and the spiral ridges are granulose in all the whorls and the furrows between them are crossed by very sharp prosocline lamellae. The uppermost two teleoconch whorls have 3–4 even, spiral ridges. *Jujubinus striatus* (Linnaeus 1758) has narrower, regular, more numerous spiral ridges (about 12 on the body whorl and 13 on the base) and lacks the prominent carina.

Genus *Gibbula* Risso, 1826

***Gibbula delgadensis* Nordsieck 1982**  
(Fig. 3)

*References for the Azores*

*Gibbula delgadensis* Nordsieck 1982. Nordsieck, 1982: 33, plate 15 (Ponta Delgada); Ávila, 2000a: 53 (São Miguel); Ávila *et al.*, 2000: 143 (São

**Table 1** Summary of the main differences between *Jujubinus pseudogravinae*, *J. gravinae*, *J. exasperatus* and *J. striatus* (Nordsieck, 1973; Cretella, 1992; Poppe & Goto, 1991).

	<i>J. pseudogravinae</i>	<i>J. gravinae</i>	<i>J. exasperatus</i>	<i>J. striatus</i>
Aperture	Quadrangular	Subcircular	Subquadrangular	Subquadrangular
Profile of the shell	High-conical	Conical	Conical, cirtoconoidal	Conical or slightly cirtoconoidal
No. whorls protoconch	1.0	1.25	1.25	1.0
No. whorls teleoconch	7	6–7	6–9	7–8
Shell colour	Variable, brown, orange-brown and olive-green, red or near black, with white or yellow flammules	Yellowish-cream, with pink, brown or greenish flammules	Light to dark red, purplish brown, greyish white or yellowish, always with traces of red or pink on the shell; white flammules sometimes present	Olive brown, greenish, cream or whitish, with brownish, chestnut or blackish flammules
Max. height (mm)	8–10	5–6	15	11–13
Max. diam. (mm)	5.5–6.5	4–5	7	7–8
Ratio height/diam.	1.33–1.37 (juveniles) 1.50–1.70 (adults)	1.20–1.45	1.25–1.85	1.20–>1.60

Miguel); Ávila, 2003: 15, 17 (São Miguel); Segers, 2002: 87 (Ponta Delgada, São Miguel); Martins, 2004: 47, 50 (Ilhéu de Vila Franca do Campo). *Gibbula* sp. 3. Macedo *et al.*, 1999: 100 (Açores).

*Type material* 3 syntypes at the Senckenberg Museum from the type locality (Ponta Delgada, no date, no collector and not yet catalogued) (Dr. Ronald Janssen, *in litt.*).

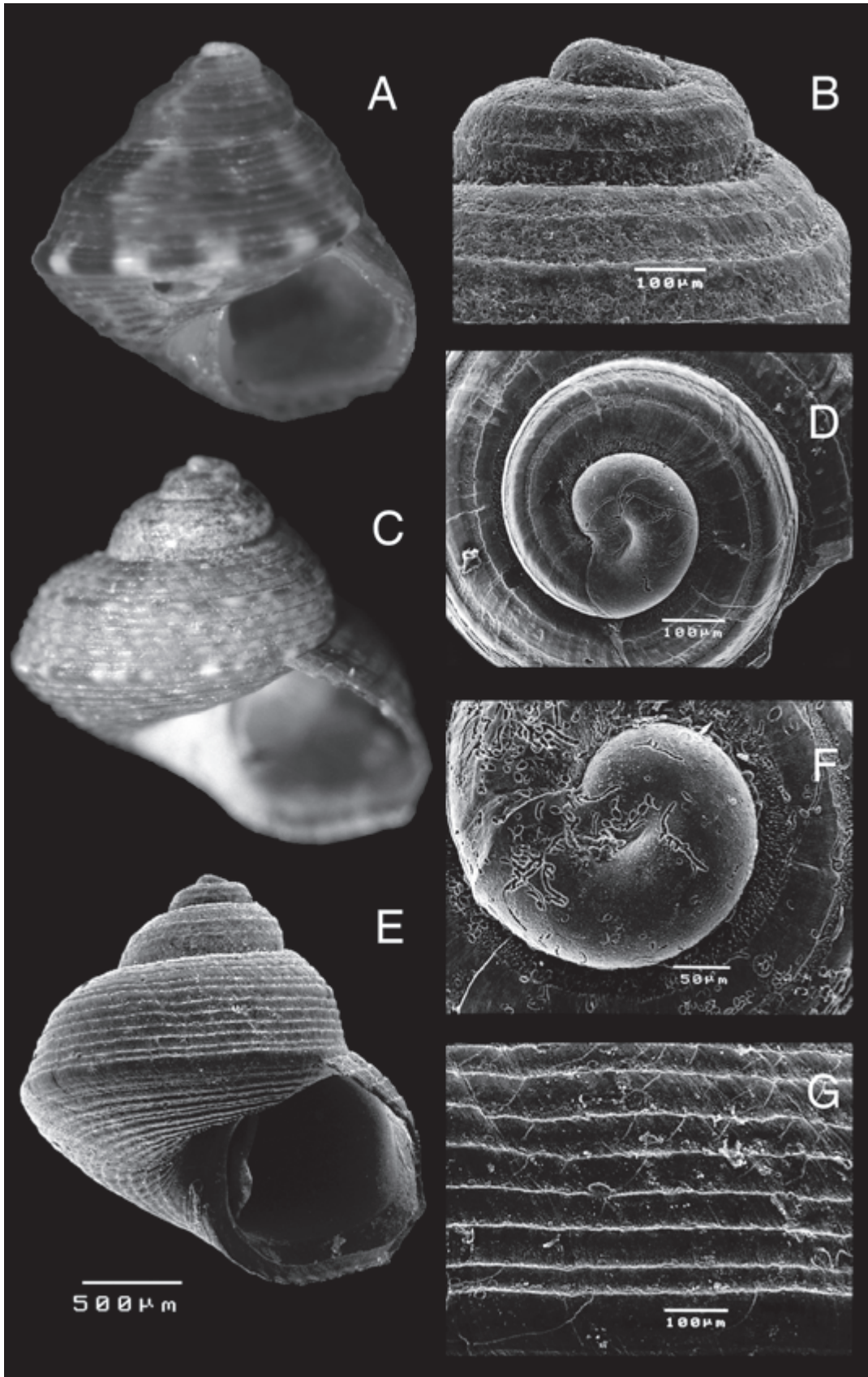
*Type locality* Ponta Delgada, São Miguel Island (Azores).

*Material examined* Flores (DBUA 568), Formigas (DBUA 320, 332, 335, 340, 342, 343, 345, 350, 353, 355), Graciosa (DBUA 057, 102), São Miguel (DBUA 117, 167, 695, 702/D, 703/B, 703/C, 708/I, 715, 733, 735, 740–741, 766, 769, 772, 781–782, 784–785, 787–789, 791).

*Description* (Fig. 3) Shell up to 2 mm in height and 2 mm in diameter, conical, solid. Protoconch 210–260 µm in diameter, smooth, with 1.1 whorls. Teleoconch with 4 convex whorls in adult specimens, covered with fine spiral cords. Cords rounded, smooth, irregularly spaced, 3 on the first whorl and 9–11 on the body whorl. The middle cord is usually larger, giving the whorls a shouldered appearance. The lower spiral cord of the body whorl is also stronger, giving the

shell a carinated profile. Base convex, with 8–11 concentric ridges, equal or narrower than the furrows. Umbilical area white with a deep, canalculated umbilicus. Aperture roughly quadrangular. Columella white, vertical or slightly prosocline. Outer lip thickened in the interior by a white callus and bordered by a dark line. Interior of the aperture nacreous. Colour of the shells cream, yellow-brown, brown, orange-brown, reddish or olive-green with white, brown or reddish flammules on the spiral cords, often arranged in irregular, longitudinal bands. Furrows between the ridges usually with nacreous iridescence. The middle and the peripheral spiral cords are usually darker than the others. Colour of base similar or slightly darker than the body whorl. Operculum multispiral, very thin, almost transparent and yellowish.

Animal whitish, with irregular red spots throughout the foot; sole of foot superficially bipartite longitudinally, dark yellow to white (Fig. 7C). Head yellowish-brown, becoming light brown on the neck and yellow on the snout, with a brown spot running down from the base of the eyestalk. Cephalic tentacles white, long, tapering, villose, the pedunculate black eyes protruding from their outer base; eyestalk whitish, with a brown stripe running along the outer side; two brown, narrow bands descend from the inner base of the tentacles and unite near the base of



**Figure 3** *Gibbula delgadensis*. **A** Syntype, apertural view: NCSM. **B** Lateral view of spire and protoconch. **C** Apertural view. **D** Top view of spire and protoconch. **E** Apertural view. **F** Top view of protoconch. **G** Detail of the microsculpture of the last whorl. B–G: DBUA 741-1/127-1.



the snout; neck lobes wide, rounded, translucent, with irregular whitish spots near their edge; three pairs of villose, white epipodial tentacles arise from the base of the epipodium; two brown papillar sense organs protrude from the posterior base of each tentacle.

*Radula rhipidoglossan* ( $\infty + 5 + 1 + 5 + \infty$ ) $\times 33$  (Fig. 8C, D). Central tooth with base very wide, first gently widening, then inflating abruptly and assuming a roughly conical shape tapering into a double neck, the anterior portion very narrow and attaching to the underneath of the crown, the posterior part flaring out and bending to continue anteriorly and form the crown; crown very small, with sharp, triangular mesocone with irregular edges appearing weakly serrated. Lateral teeth becoming gradually larger, the basis flaring outwards, with outer margins of the first four teeth sharply bent, becoming gently rounded on the last; crown of the first lateral slightly larger than that of the central tooth, with mesocone, sharp, endocone with three and ectocone with four conspicuous, subequal cusps; second lateral similar to the first, the crown twice the size of that of the first lateral, cusps blunt; third to fifth laterals with crowns becoming larger, elongated and blunt; mesocone, endocone and ectocone with three cusps. Marginal teeth very narrow, the first five with long, broad, tricuspidate crown, mesocone long and rounded, endocone and ectocone sharp; from the sixth marginal outwards the mesocone narrows gradually and the endocone and ectocone become first bicuspid, then tricuspid and eventually pectinate. *Ecology* Specimens were found usually associated to algae, under or over rocks.

*Bathymetric range* Intertidal down to 30 m, more common in the first 10 m (Ávila, 2003: 17, fig. 3).

*Geographic distribution* Endemic to the Azores, occurring in all three island groups.

*Fossil record* Reported by Ávila *et al.* (2002) and Ávila (2005) to Prainha outcrop (Pleistocene) (Santa Maria Island) (DBUA-F 45, 139).

*DNA Sequences* Partial sequences of the 16S rRNA mitochondrial gene (Genbank EF469255) and 18S rRNA (Genbank EF469256), and of the internal transcribed spacer 1 (ITS1) (Genbank EF469257).

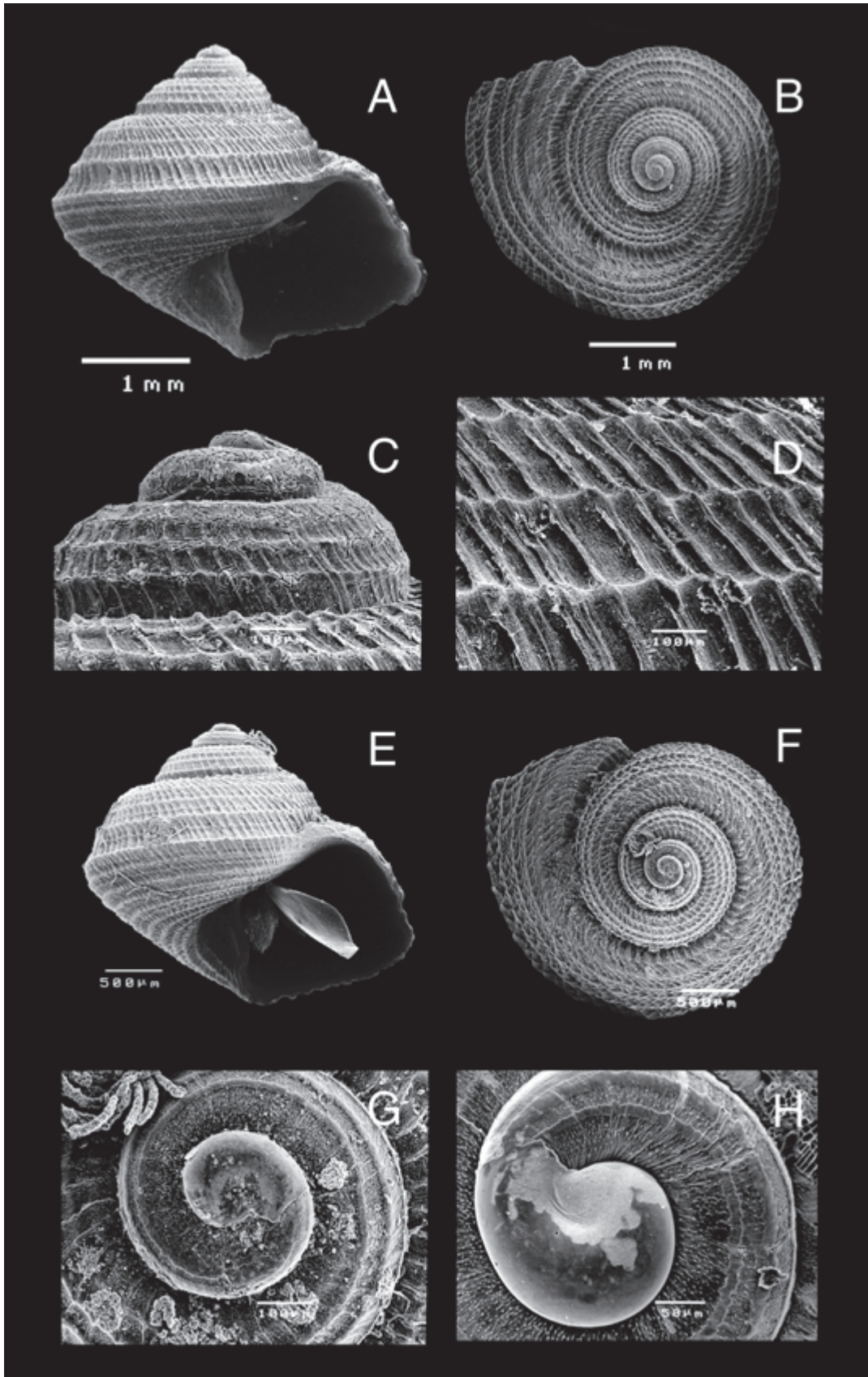
### *Gibbula magus* (Linnaeus 1758) (Fig. 4)

#### *References for the Azores*

*Trochus magus* Linnaeus 1767. Drouët, 1858: 29 (São Miguel, Rosto do Cão).  
*Gibbula magus* (Linnaeus 1758). Dautzenberg, 1889: 63 (Faial, Horta, -15 to -20 m, Stn. 103, "Hirondelle", 1887); Ávila & Azevedo, 1996: 106 (Pico); Morton *et al.*, 1998: 88, 144 (Azores); Ávila, 2000a: 52–53 (São Miguel); Ávila *et al.*, 2000: 143 (São Miguel); Segers, 2002: 86 (Azores); Martins, 2004: 50 (Ilhéu de Vila Franca do Campo).  
*Gibbula magus* (Linnaeus 1767). Dautzenberg, 1889: 63 (São Miguel, Rosto do Cão); Bullock, Turner & Fralick, 1990: 45 (São Miguel, Ponta da Galera; Queimada, Água d'Alto; Mosteiros; Calheta, Ponta Delgada; Ilhéu de Vila Franca); Morton & Britton, 1995: 70 (São Miguel, off Vila Franca do Campo).

*Material examined* Faial (DBUA 410, 421, 422, 424), Pico (DBUA 661, 670), São Miguel (DO 70; DBUA 021, 117, 167, 168, 169, 170, 604, 605, 607, 608, 609, 614, 616, 618, 621, 624, 655, 676, 696, 709, 717, 719, 731, 732, 734, 735, 737, 739, 784, 807).

*Description* (Fig. 4) Shell height up to 12 mm, diameter 14 mm, depressed, solid. Height/diameter ratios between 0.80–0.83 (juveniles) and 0.87–0.91 (adults). Protoconch 210–260  $\mu$ m in diameter, with 1.1 whorls, smooth. Teleoconch with 4 convex whorls in adult specimens, covered with fine spiral cords. Cords rounded, smooth, irregularly spaced, 3 on the first whorl and 9–11 on the body whorl. The middle cord is usually larger, giving the whorls a shouldered appearance. The lower spiral cord of the body whorl is also stronger, giving the shell a carinate profile. Base convex, with 8–11 concentric ridges, equal or narrower than the furrows. Umbilical area white with a deep canaliculated umbilicus. Aperture roughly quadrangular. Columella white, vertical or slightly prosocline. Outer lip thickened in the interior by a white callus and bordered by a dark line. Interior of the aperture nacreous. Colour of the shells cream, yellow-brown, brown, orange-brown, reddish or olive-green with white, brown or reddish flammules on the spiral cords, often arranged in irregular, longitudinal bands. Furrows between the ridges usually with nacreous iridescence. The middle and the peripheral



**Figure 4** *Gibbula magus*. **A** Apertural view. **B** Top view. **C** Lateral view of spire and protoconch. **D** Detail of the microsculpture of the last whorl. **A–D**: DBUA 424/120-2. **E** Apertural view. **F** Top view. **G** Top view of spire and protoconch. **E–G**: DBUA 168/118-1. **H** Top view of protoconch: DBUA 424/120-1.

spiral cords are usually darker than the others. Colour of base similar or slightly darker than the body whorl. Operculum multispiral, very thin, almost transparent and yellowish.

Animal light brown, mottled with dark-brown irregular patches on the upper posterior half of the foot, lower portion of the foot with dense white spots over a pale background (Fig. 7D). Head light brown. Cephalic tentacles greyish, translucent, long, tapering, villose, the pedunculate blue eyes with black iris protruding from their outer base; eyestalk golden-brown; neck lobes rounded, translucent, with irregular whitish spots, right lobe wide, left one narrow, pointed; three pairs of long, villose, greyish epipodial tentacles arise from the base of the epipodium,; a white papillar sense organ protrudes from the lower base of each epipodial tentacle.

Radula rhipidoglossan ( $\infty + 5 + 1 + 5 + \infty$ ) $\times 64$  (Fig. 8E, F). Central tooth with base very wide, an anterior portion narrowing to form the support of the crown, the posterior portion flaring outwards as it bends up to form the crown; crown relatively small, depressed posteriorly, with sharp, triangular mesocone with serrated edges on posterior half. Lateral teeth with bases slightly flaring outwards at about mid-length, outer margins of the posterior portion forming the crown expanded outwards; crown of the first lateral slightly about the same size as that of the central tooth, crown of the remaining laterals becoming progressively longer, the endocone with three sharp cusps, the ectocone with five conspicuous, cusps decreasing posteriorly. Marginal teeth very narrow, with long, falciform crown.

*Bathymetric range* More common between 5 and 20 m, in coarse gravel bottoms (Costa & Ávila, 2001).

*Geographic distribution* Scandinavia, Belgium, British Isles, Bay of Biscay, Portugal, Mediterranean, Madeira, Canary Islands and in all islands of the Azores (Ávila, 2005).

*Fossil record* Reported by Ávila *et al.* (2002) from the Prainha outcrop (Pleistocene) (Santa Maria Island) (DBUA-F 45, 91).

*Remarks* The Azorean specimens (both fossil and recent) are much smaller than the European ones (25 to 35 mm in diameter; Poppe & Goto,

1991: 80) (Fig. 4). The largest shell found in the Azores, was a fossil specimen (DBUA-F 91; 1.32 $\times$ 0.99 cm) reported by Ávila *et al.* (2002: 349, Figs 15–16) from Santa Maria Island. This phenomena (the dwarfism of insular specimens) was also reported by Simone (in press), in gastropods of the islands of the São Pedro and São Paulo archipelago (Brazil).

Family Calliostomatidae Thiele 1924

Genus *Calliostoma* Swainson 1840

***Calliostoma lividum* Dautzenberg 1927**

(Figs 5, 6)

*References for the Azores*

*Trochus zizyphinus* Linnaeus 1758. MacAndrew, 1856: 119, 147 (misidentification) (Azores).

*Trochus laugierii* (Payraudeau 1826). MacAndrew, 1856: 120, 147 (misidentification) (Azores, 7 to 20 m).

*Trochus conulus* Linnaeus 1766. Drouët, 1858: 29 (misidentification) (São Miguel).

*Trochus (Zizyphinus) zizyphinus* Linnaeus 1758. Watson, 1886: 696 (misidentification) (off Faial, 80 to 150 m, Stn. 75, "Challenger", 1873).

*Trochus dubius* Philippi 1844. Simroth, 1888 (misidentification) (São Miguel, Ponta Delgada).

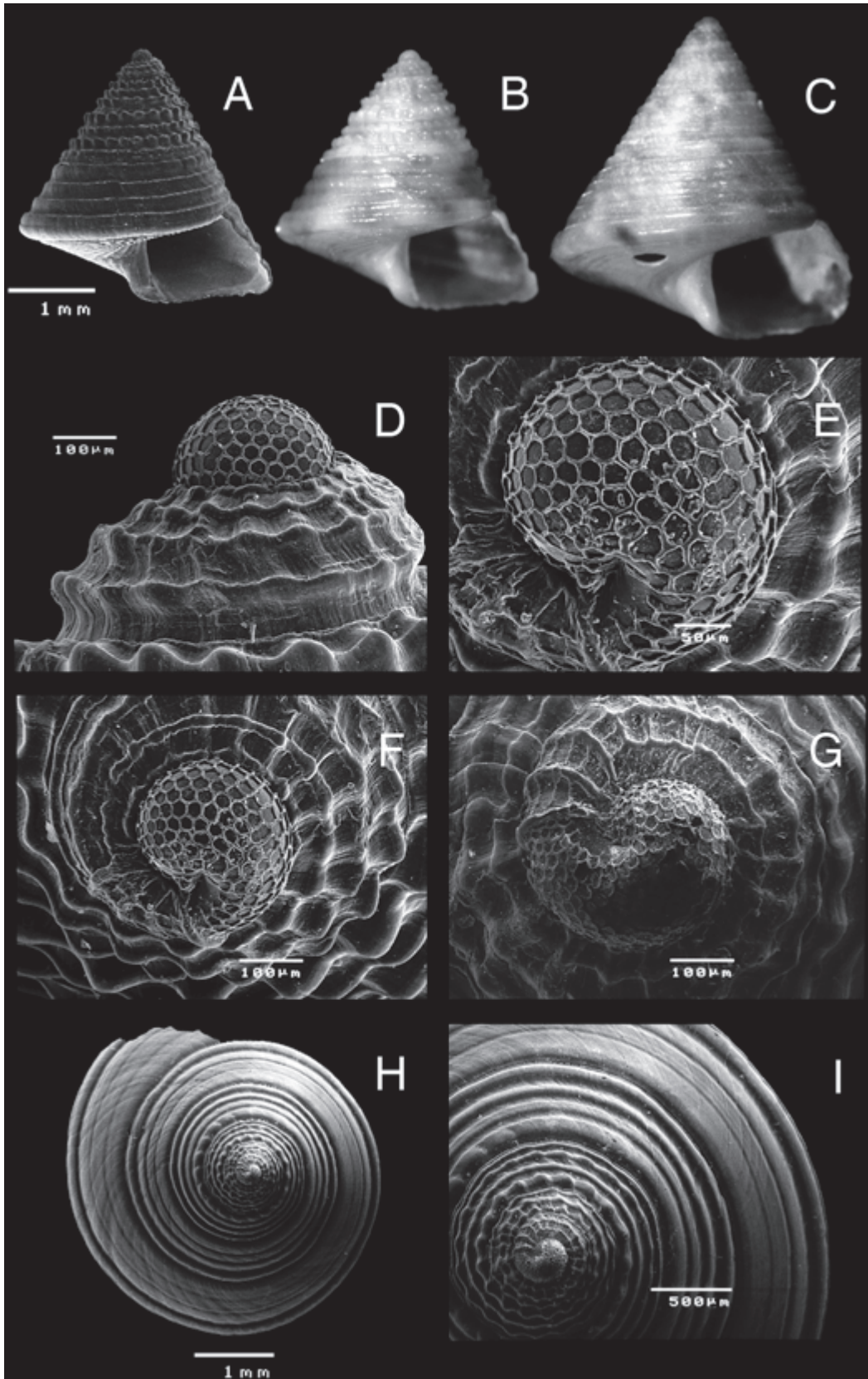
*Calliostoma conuloides* Lamarck 1822. Dautzenberg, 1889: 62 (Faial, Horta, -15 to -20 m, Stn. 103, "Hirondelle", 1887); Nobre, 1924: 82 (misidentification) (São Miguel, Ponta Delgada); Nobre, 1930: 59 (misidentification) (São Miguel, Ponta Delgada).

*Calliostoma conulus* (Linnaeus 1758). Dautzenberg, 1927: 190–191 (between Pico and Faial, Stn. 226, 130 m depth; Stn 882, 98 m depth).

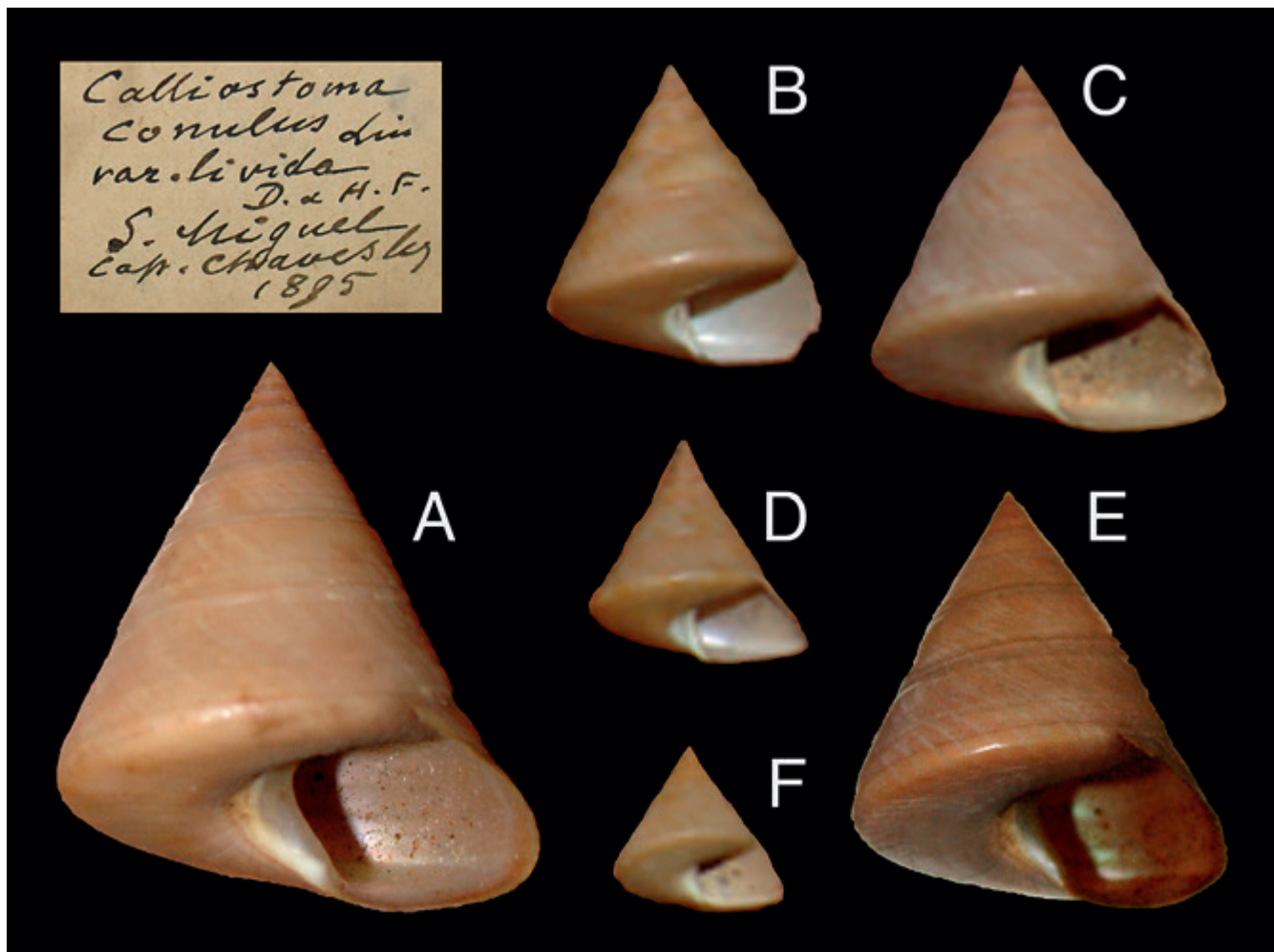
*Calliostoma conulus* (Linnaeus 1758) var. *livida* Dautzenberg 1927. Dautzenberg, 1927: 191 (Terceira (Sto. António, Stn. 594, 54 m depth), between Pico and Faial (Stn. 882, 98 m depth), between Pico and São Jorge (Stn. 1349, 1,250 m depth) and São Miguel).

*Calliostoma* sp. Azevedo & Gofas, 1990: 84 (Flores, Santa Cruz); Ávila *et al.*, 2000: 143 (São Miguel); Ávila, 2003: 32–33 (São Miguel); Segers, 2002: 86 (Azores); Ávila *et al.*, 2004: 77 (Banco D. João de Castro); Martins, 2004: 50 (Ilhéu de Vila Franca do Campo).

*Calliostoma zizyphinum* (Linnaeus 1758). Azevedo, 1991: 20 (São Miguel, Ribeirinha); Morton *et al.*, 1998: 144 (misidentification) (Azores).



**Figure 5** *Calliostoma lividum*. **A** Apertural view. **B** Apertural view. **A, B**: DBUA 766/123-1. **C** Apertural view: DBUA 698/126-1. **D** Lateral view of spire and protoconch. **E** Top view of protoconch. **F** Top view of spire and protoconch. **D-F**: DBUA 766/123-1. **G** Top view of spire and protoconch. **H-I**: DBUA 356/128-1.



**Figure 6** *Calliostoma lividum*, apertural views. All, Dautzenberg Collection (DC-RBINS, Brussels). A 21.1×17.9 mm. B 13.1×12.4 mm. C 19.4×16.3 mm. D 10.2×10.0 mm. E 22.8×11.1 mm. F 15.3×14.5 mm.

*Calliostoma* cf. *conulus* (Linnaeus, 1758). Ávila, 2000a: 53 (misidentification) (São Miguel).

*Calliostoma lusitanicum* Nordsieck & Talavera 1979. Wirtz & Debelius, 2003: 165 (misidentification) (Azores).

**Type material** The type material was collected by Cap Chaves in São Miguel Island and consists of two samples with 12 shells, which are at RBINS, under the reference DC-RBINS I.G. 10591. These 12 shells were classified by Dautzenberg (1927) as *Calliostoma conulus* var. *livida* (Fig. 6). There is also another sample not examined by the authors, with 2 shells from São Miguel Island, collected by Crosse & Drouët and classified in the Dautzenberg collection as *Calliostoma conulus* var. (without further indication) (Thierry Backeljau pers. comm.).

**Type locality** São Miguel Island (Dautzenberg, 1927: 191).

**Material examined** Banco D. João de Castro (DBUA 813, 814, 839), Faial (*ImagDOP* s110-4, s225-19; DOP/ML 0003, 0021; DBUA 433), Flores (DBUA 557, 565, 579), Formigas (DBUA 330, 338, 339, 355, 356, 362, 365), Pico (DBUA 668, 670, 672, 677, 796), São Miguel (DO 16; DBUA 605, 634, 651, 652, 654, 657, 675, 676, 682, 683, 688, 695, 696, 697, 699, 712, 719, 724, 732, 738, 748, 755, 758, 766, 767, 773, 776, 777, 779, 780, 781, 782, 783, 785, 787, 789, 838).

**Description** (Figs 5, 6) Adults up to 26 mm in height, 22 mm in diameter. Height/diameter ratios between 1.00–1.16 (juveniles) and 1.09–1.29 (adults). Body whorl about 53% of total

height of shell, aperture 48%. Shell solid, opaque, conic and nearly straight-sided except in body whorl. Nucleus with rounded tip; protoconch with about 1 whorl, 270–320  $\mu\text{m}$  across, and with typical hexagonal honeycomb reticulate pattern. Teleoconch with about 10 whorls in adult specimens. First teleoconch whorl convex, with 3 spiral cords, following whorls flat; up to fifth whorl with 4–5 granulated spiral cords and after fifth whorl with flatter cords, so on last whorls only very narrow furrows to be seen; these furrows unequal in size, irregularly spaced and more evident in lowest part of whorl. Body whorl sometimes somewhat concave in uppermost part and rounded at periphery. Base slightly convex with same sculpture as body whorl. Whole shell, including base, crossed by numerous, visible, strongly prosocline growth lines. Umbilicus closed even in juveniles. Aperture of shell prosocline and always rounded. Outer lip thin, arising at the peripheral keel of the previous whorl. Columella prosocline, nacreous, bordered by a white callus, forming a denticle in its lowest part. Interior of the aperture nacreous with pink refulgence. Colour of shells apparently uniform dark grey-greenish but consisting of grey background with irregular blotches or tonalities of brown, greenish-brown and violet. Protoconch and first whorls of teleoconch with a more rose-violet tonality. Base same colour as body whorl.

Operculum multispiral, thin, yellowish-brown with the periphery white and covered by numerous growth lines.

Animal reddish-brown with darker, longitudinal striations along foot; sole of foot pinkish, edges white (Fig. 7E, F). Head and snout uniform brown. Cephalic tentacles brown, long, tapering, pedunculate blue eyes protruding from their outer base; eyestalk brown; neck lobes wide, rounded, brown with whitish edge, fusing to foot at its mid-length and continuing posteriorly as a papillose epipodial crest that joins to dorsal edge of tip of the foot; four pairs of light-brown epipodial tentacles arise from each side of base of epipodium, the anterior-most longest, arising underneath the posterior junction of neck lobe, the remaining gradually diminishing in length posteriorly; a whitish papillar sense organ protrudes from the ventral base of each tentacle.

Radula rhipidoglossan ( $\infty+2$ ) + (1+4) + 1 + (4+1) + (2+ $\infty$ ) $\times$ 130 (Fig. 8G, H). Central tooth with wide base, abruptly tapering toward the neck; crown

relatively wide, thin, tapering down into a sharp, long, triangular mesocone with finely serrated edges. First four lateral teeth with wide, thin base and very narrow, long, falciform, pectinated crown; fifth lateral tooth very strong, falciform, the crown rounded with weakly serrated rim, projecting downward as a strong blade with five denticulations, the posterior one strongest and gradually diminishing anteriorly. Marginal teeth very narrow, falciform, the first two with strong, non-serrated crown, maintaining the denticulated, downward projection as present in the fifth lateral tooth; remaining lateral teeth, falciform with narrow, pectinate crown.

*Ecology* Specimens were found usually over and under rocks, especially in vertical walls and are more active during night.

*Bathymetric range* From low tide, where it is uncommon, down to 40 m depth. Although not a common species, it is more abundant between 15–22 m depth (Ávila, 2003).

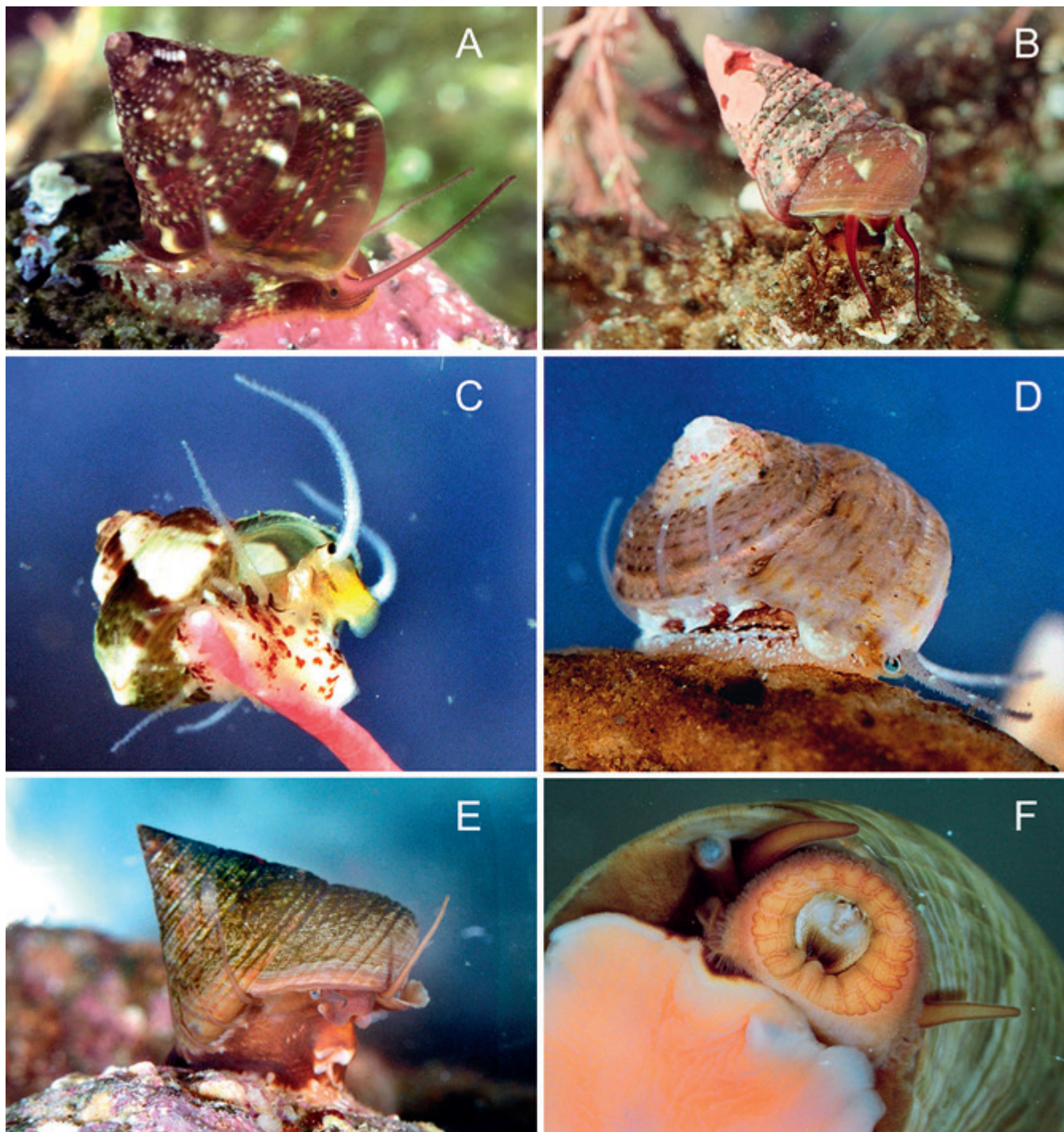
*Geographic distribution* Endemic to the Azores, occurring in all three island groups.

*Fossil record* Reported as *Calliostoma zizyphinum* (Linnaeus 1758) for Lagoinhas outcrop (Santa Maria Island) by Callapez & Soares (2000: 314). Reported as *Calliostoma* sp., by Ávila *et al.* (2002) from both Prainha and Lagoinhas outcrops (Santa Maria Island) (DBUA–F 87, 138, 140).

*Remarks* Dautzenberg (1927) referred to this species as a new variety of *C. conulus*, "*Calliostoma conulus*, Linné var. *livida*, nov. var.: Tandis que le *C. conulus* typique a une coloration jaune orangée plus ou moins foncée, cette variété est d'un gris livide, un peu rosé vers le sommet de la coquille".

*Calliostoma lividum* is a very constant species in form, sculpture and colour of the shell. It has an average ratio height/diameter of 1.17 (mean of 35 specimens, ranging from 1.00 to 1.39), higher than that of *Calliostoma conulum* (mean of 1.11) or *Calliostoma zizyphinum* (ranging from 1.00 to 1.04). The protoconch is similar to that of *Calliostoma zizyphinum*.

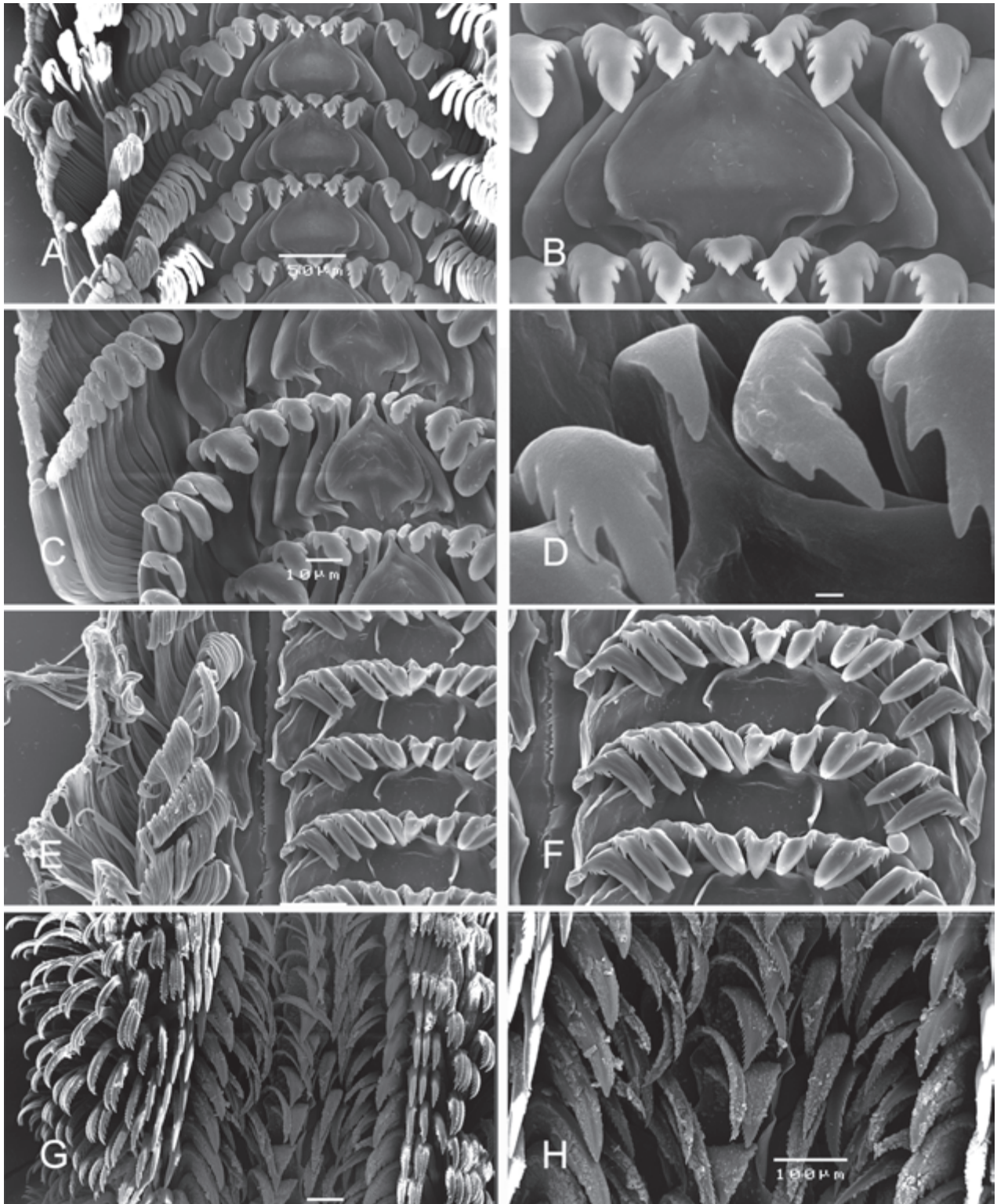
*Calliostoma conulus* has a very shiny, more or less dark orange-coloured shell. The first whorls are more granulose and the following ones usually smoother than in *C. lividum*. Also,



**Figure 7** Live Trochoidea of the Azores. **A, B** *Jujubinus pseudogravinae*. **C** *Gibbula delgadensis*. **D** *Gibbula magus*. **E, F** *Calliostoma lividum*.

a suprasutural cord, usually with brown and white flammules, is always present. The basal periphery is angulated, with a prominent carina. The base has concentric brown lines with white spots, never present in *C. lividum*. The suture is channelled, in contrast with that of *C. lividum* and *C. zizyphinum* in which it is impressed.

*Calliostoma zizyphinum* has the upper part of the spire rather concave and more granulose than in *C. lividum*. The last whorls are more spirally sculptured and a prominent broad carina is present in the periphery of the body whorl. The colour of the shell is also distinct and the number of whorls of the teleococonch may be up to



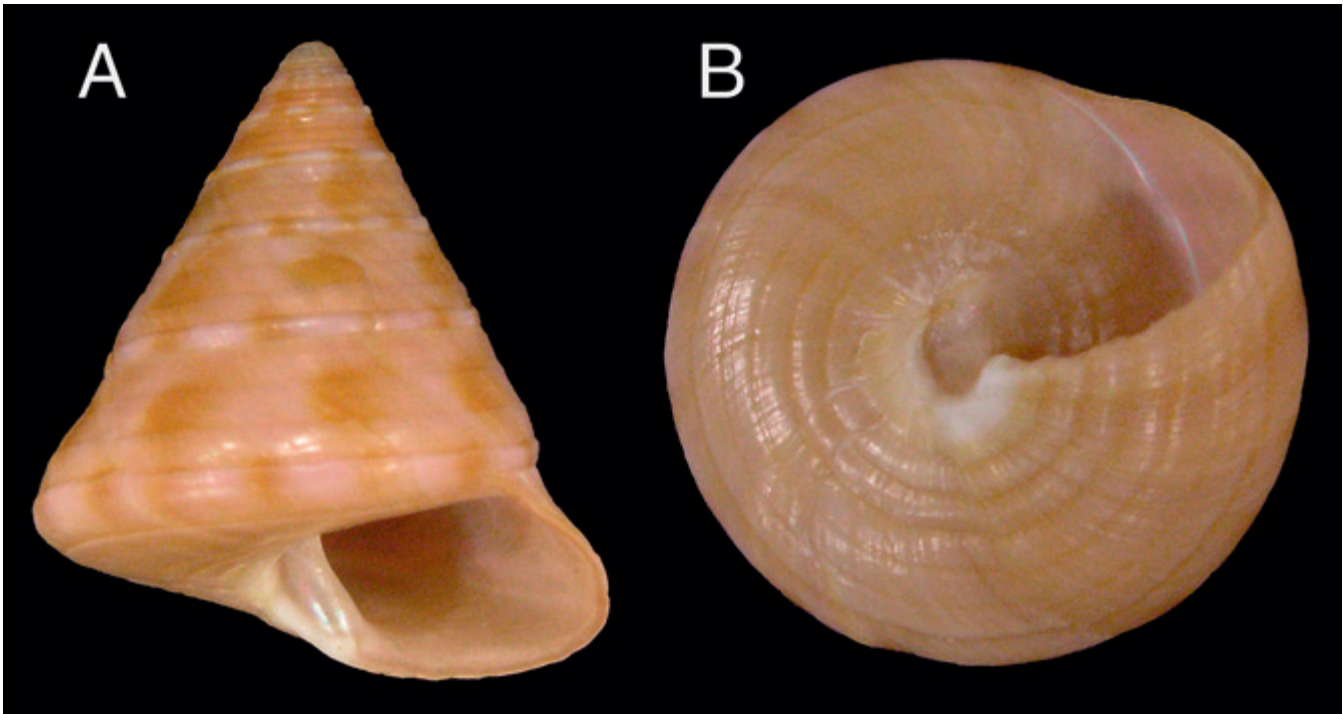
**Figure 8** Radula of the Trochoidea of the Azores. **A, B** *Jujubinus pseudogravinae*; **C, D** *Gibbula delgadensis*. **E, F** *Gibbula magus*. **G, H** *Calliostoma lividum*.

13 whorls, in contrast with just 10 in *C. lividum* and 10–11 in *C. conulum*.

*Calliostoma laugierii* (Payraudeau 1826) has similar shell colouration to *C. lividum*, but with

conspicuous brown dots and flammules. Brown lines with white spots are also present on the base. The first whorls are less granulated and a supra-sutural carina is evident. The average size





**Figure 9** *Calliostoma lusitanicum* (holotype; Museo de Ciencias Naturales de Tenerife). **A** Apertural view. **B** Bottom view.

(12 mm in height, Poppe & Goto, 1991: 74) is smaller than that of *C. lividum*.

Wirtz (2001: 135) shows a picture of a calliostomatid species from Madeira which is very similar to the Azorean *C. lividum*. However, he identified it as *Calliostoma lusitanicum* Nordsieck & Talavera 1979, a species referred to in the CLEMAM database as *Trochoidea incertae sedis*, and thus a nominal taxon in need of reassessment. Wirtz & Debelius (2003: 165) also show a picture of the Azorean *Calliostoma* species and refer to it as *Calliostoma lusitanicum* reported from the Madeira, Selvagens and Canary Archipelagos, with a distinct brown yellow colouration and a more prominent suprasutural cord. The holotype of *C. lusitanicum* deposited in the Museo de Ciencias Naturales de Tenerife is here illustrated (Fig. 9).

#### DISCUSSION

Six littoral species of Trochoidea are reported from the Azores, of which two are dubious records (*Clanculus bertheloti* and *Gibbula umbilicalis*), three are endemic (*Jujubinus pseudogravinae*, *Gibbula delgadensis* and *Calliostoma lividum*) and

one has a wide distribution in the North Atlantic (*Gibbula magus*). There is therefore a high proportion of endemic trochoideans in this isolated archipelago.

The four trochoidean species that are reported from the Azores are present in all the islands of the archipelago. The nine islands of the Azores are distributed in 3 groups (Western, Central and Eastern) with distances that range between about 240 km (Western-Central) and 170 km (Central-Eastern). These geographical distances seem to be within the dispersal capabilities of the Azorean trochoideans. Madeira archipelago is the next nearest landmass, but the 900 km that separate these archipelagos is apparently too much to permit genetic exchange.

It is well known that both the Trochidae and Calliostomatidae have larvae with a short pelagic life (Gofas, 2005). This fact probably prevents long-distance dispersal, but once in the islands, the "lucky" immigrants may establish viable populations and, due to the absence of genetic exchange with outer archipelago populations, differentiate from the putative continental (or other insular) source populations. This may be the reason for the high number of endemic species of trochids s.l. in the Azores. Ávila (2005)

reported 354 shallow water marine mollusc species in the Azores archipelago. Of these, 22 are pelagic species, and 5 are considered to be introduced (Cardigos *et al.*, 2006) so there are 327 benthic species presently living in the shallow marine realm of the Azores. The endemic element consists of 34 species (10.4%), with the Rissoiidae accounting for almost half (16 species), followed by the Pyramidellidae (3 species), and the Trochidae, Caecidae and the Conidae (2 species each). Eleven other families each contribute a single species to the Azores endemic component: Calliostomatidae, Cystiscidae, Elachisinidae, Ellobiidae, Eubranthidae, Gymnodorididae, Marginellidae, Muricidae, Tricoliidae and Triphoridae among the Gastropods, and the Neoleptonidae among the Bivalves.

Trochids are adapted to clean, clear waters and oceanic islands present a natural habitat for the group. Owing to the immense volume of ocean surrounding them, the Azores still enjoy nearly pristine water conditions. Their coastline, however, is narrow and fragile, and is frequently threatened by runoff from land, mainly due to agricultural activities which leave the soil unprotected against heavy rains. Suitable habitats, then, could rapidly disappear and their slow recovery may not prepare them in time for the next runoff, thus gradually weakening the health of their resident populations. The survival of the shallow-water trochid populations on these islands is, then, very dependent upon the perturbations imposed on the nearby land mass by human activity.

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