ISSN 1053-637X

WALKERANA

Transactions of the POETS Society

Vol. 8 No. 19

Ann Arbor, Michigan
1995-1996

WALKERANA

A Journal of Molluscan Biology

Transactions of the POETS Society

Vol. 8, No. 19

Volumes, years and numbers of *Walkerana* are as follows: Vol. 1 (1980-83), nos. 1-5; Vol. 2 (1984-88), nos. 6-8; Vol. 3 (1989), nos. 9, 10; Vol. 4 (1990), nos. 11, 12; Vol. 5 (1991), nos. 13, 14; Vol. 6 (1992), nos. 15, 16; Vol. 7 (1993-1994), no. 17/18; Vol. 8 (1995-1996), nos. 19, 20.

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Walkerana
P. O. Box 2701
Ann Arbor, Michigan 48106
U.S.A.

Walkerana, 1995-1996, 8(19): 1-30

H. BURRINGTON BAKER'S ANATOMICAL NOMENCLATOR

H. Burington Baker[1], Yoshio Kondo[2] and John B. Burch[3]

Two of the outstanding molluscan anatomists of the past generation were Horace Burrington Baker and Yoshio Kondo. Both studied land snails. Dr. Baker, after receiving his Ph.D. degree from the University of Michigan in 1920, was on the faculty of the University of Pennsylvania, and was affiliated as Research Associate and Fellow at the Academy of Natural Sciences of Philadelphia from 1925 until his death in 1971. He was also a Research Associate at the Bernice P. Bishop Museum, Honolulu, from 1937 until 1971. Dr. Baker was not only a fine anatomist but also an excellent illustrator, who published many scholarly, well illustrated papers on land snail taxonomy and anatomy[4]. [Many of Dr. Baker's figures and accompanying data were used in Henry A. Pilsbry 's (1939-1948) monumental *Land mollusks of North America (north of Mexico)*.]

Dr. Yoshio Kondo was a malacologist at the Bernice P. Bishop Museum from 1934 until his death in 1990. His main malacological interest was in the land snails of the Pacific oceanic islands, especially the families Achatinellidae, Amastridae and Partulidae. Kondo, too, was a superb anatomist and illustrator, and, like Dr. Baker, was an excellent collector and spent much time collecting land snails on Pacific islands, beginning with the Mangareva Expedition in 1934. Dr. Kondo received his Ph.D. degree from Harvard University in 1955. Dr. Kondo was influenced by Dr. Baker when the latter spent eight months at the Bishop Museum studying the Zonitidae of the Pacific islands. That was at an early stage in Dr. Kondo's career, and it was at that time that he became an anatomist[5].

The junior author (Burch) of this article was also influenced by Dr. Baker, as well as by Dr. Kondo, with whom he was closely associated from 1960 until Dr. Kondo's death. Burch made many visits to the Bishop Museum, where, since 1966, he has been a Research Associate. He has three joint research publications with Dr. Kondo, as well as a

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[4] For a short description of Dr. Baker's life, see Abbott & Wirtz (1971).

[5] For a short description of Dr. Kondo's life, see Burch (1994).

large monograph on the Partulidae in preparation.

One of the research aids provided by Dr. Kondo during this collaborative research period was the document carefully assembled, typed and edited by Kondo, "H.B. Baker's Anatomical Nomenclature." The junior author has since given copies of this document to interested malacologists, and is now making it available, in an edited form, to a wider audience.

ANATOMICAL TERMS

Abdominal: pertaining to abdominal ganglion (see ganglia, connective and nerve).
Accessory plate: see radula.
Acoustic nerve: see nerve.
Acrecbolic and **acrembolic:** see introvert.
Adrectal gland: gland on side of rectum; see also anal gland.
Admedian: see radula; lateral tooth.
Aglossate: without radula.
Agnatha: without jaw.
Albumen gland: compound alveolar gland emptying by duct(s) into carrefour; imbedded in liver just apical to lung; *synonym* albuminiparous gland.
First accessory albuminiparous gland (F.C. Baker, 1911); oviducal bulb (H.B. Baker, 1925b) or uterus.
Second accessory albuminiparous gland (F.C. Baker, 1911): nidamental gland (F.C. Baker, 1911) or oviducal diverticulum (H.B. Baker, 1925b).
Anal: pertaining to anus.
Anal glands: (Streptoneura) special glands; (Pulmonata) mantle gland between hindgut and ureter.
Anal nerve: see nerve.
Angle (angular) or **parietal angle**: junction between parietal and palatal sides of mantle collar (or shell aperture); see also atrium.
Angulopalatal: on palatal side near angle; commonly anterior to pneumostome, on right side of animal; see mantle lappet.
Anteriad or craniad: anteriorly.
Anterior or cranial: towards head.
Anus (anal): external aperture of rectum; often near parietal angle.
Aorta (aortic): large artery from ventricle; it passes outside of intestinal S-loop and forks into cephalic and visceral aortae.
Cephalic aorta: usually passes, inside of hindgut, to apex of uterus and then runs anteriad towards head.
Visceral aorta: to apical viscera.
Aperture: any external opening; also that of shell.
Aphallic: without a penis.
Apical: towards apex of spire; see gonaduct, posterior and viscera. Also, towards free end of any organ; tip of introvert (*e.g.*, penis) is apical in both senses.
Appendicle or **appendicula** (appendicular): a small appendix; (Pilsbry, 1894) vaginal appendicle.
Appendix (appendical): a long, apical, blind pouch or caecum.
Artery (arterial): tube carrying blood away from heart.
Atrium (atrial): a vestibule (Pilsbry, 1894) common chamber into which male and fe-

male organs open; *syn.* genital atrium, cloaca, and vestibule or genital vestibule. Also means auricle of heart.
Atrial or peniovidúcal angle: that between penis and vagina.
Atrial aperture: external genital opening, commonly near right inferior tentacle.
Atrial appendix or caecum: apical blind pouch.
Atrial diverticulum or lobe: lateral or basal pouch.
Atrial gland: often a glandular zone.
Atrial prepuce of penis: (Microcystinae, H.B. Baker, 1938) a. branch, into which penis and spermatheca open.
Atrial retractor: see retractor.
Atrial sac: see vestibule a. dart-sac, and atrial (vagina)
Atrial stimulator: see stimulator.
Atrial vagina: (Dyakiinae, H.B. Baker, 1941): a. branch into which dart apparatus and spermatheca open.

Auditory nerve: see (acoustic) nerve.
Aulacopod: with double peripodial grooves.
Auricle (auricular) or atrium of heart: chamber into which veins enter.
Auricular gland: see pericardium (gland).
Azygous or azygo-: (gastropods) usually means unpaired, *i.e.,* with one organ (usually left) of a primitive pair, as in azygobranch (with only left ctenidium) or asygogonaduct (right one).

Basal: towards umbilical side of shell; see shell lobe.
Basement membrane: see radula.
Basopalatal: near basal end of palatal side; see mantle lappet.
Belum (belic): dart, on female organs.
Body: part outside of mantle or shell; see foot.
Body cavity: nemocoele in head and foot; (Pulmonata) pleuropedal, often extends to near posterior (apical) wall of lung, and surrounds secondary gonaducts, esophagus, buccal bulb, ganglia and many retractors.
Body lappets or body lobes: mantle (lappets).
Body wall: sides of body cavity. Body whorl: last whorl.
Branchion (pl. branchia) (branchial): respiratory appendage.
Accessory branchion: pseudobranch.
Pallial branchion: any true branchion (ctenidium) or accessory branchion on mantle.
Buccal (B): pertaining to cavity behind mouth; *syn.* pharyngeal; see (buccal) commissure, connective, nerve and retractor.
Buccal bulb or mass: muscular enlargement behind mouth; it contains radula and receives esophagus and ducts of salivary glands; *syn.* pharynx.
Buccal crypts: patches of mucous cells.
Buccal opening: the "true" mouth.
Buccal plate: jaw.
Buccal veil: *(Aplysia)* paired labial expansions.
Buccoretractor: see (buccoretractor) nerve.
Bursa (bursal) or **bursa copulatrix:** spermatheca.

Caecum (caecal): a blind pouch or lobe, usually apical.
Calc-sac: see epiphallus (flagellum or caecum).
Canalis junctor: (Veronicellidae) duct from vas to spermatheca.
Capituliform complex: see radula.
Capreolus: spermatophore.

Carditogenital nerve: see nerve

Carrefour: ("cross-roads"; Lacaze-Duthiers, 1899): (Pulmonata) sac near posterior (apical) lung-wall; it receives ovisperm duct, talon and ducts of albumen gland, and is continued by spermoviduct proper or gives off oviduct (uterus) and spermiduct; (neritoids) see thalamus; *syn.* fertilization (?) chamber, uterus (F.C. Baker, 1911) and spermoviduct (H.B. Baker, 1925a).

Caudad: caudally.

Caudal (caudo-): pertaining to or towards tail; see (caudal) nerve and retractor.

Caudal foss: dorsal cavity or pore, lined with mucous cells, near tip of tail; *syn.* caudal boss (when overted) and caudal mucous pore or gland.

Caudal "horn": fleshy projection near tip of tail, often above caudal foss.

Caudal sulcus: mid-dorsal groove on tail.

Central or **centrifugal:** see radula; middle tooth or away from it.

Cephalic: pertaining to head; see frontal (lobe) and (cephalic) aorta or (cephalic) tentacle.

Cerata (plural of ceras): (nudibranchs) large mantle-processes or accessory branchiae.

Cerebral: pertaining to cerebral ganglion; see (cerebral) ganglion, commissure and nerve.

Cerebrobuccal: see (buccal) connective.

Cerebropedal: see (pedal) connective.

Cerebropleural: see (pleural) connective.

Cervical (neck) **lobe:** the one on the epipodium.

Chiastoneury (chiastoneurous): see streptoneury.

Circulatory system: includes heart (pump), arteries, blood sinuses (see haemocoele) and veins.

Cloaca (cloacal): the (genital) atrium.

Coelome [coelom] (coelomic): mesothelial body-cavity; applied in mollusks to pericardial and gonad cavities.

Coelomic duct: coelomoduct.

Coelomoduct (coelomoducal): one of paired (right and left) ducts from coeloms; (mollusks) applied to primary uroducts and gonaducts.

Pericardial coelomoduct: primary uroduct.

Columellar: pertaining to columellar retractor; see retractor and nerve.

Comb lateral: see radula.

Commissure: unpaired nerve connection between right and left ganglia of same name.

Abdominal commissure: between paired abdominal ganglia (seldom used); *syn.* visceral commissure; *syn.* visceral connective.

Buccal commissure: subesophageal.

Cerebral commissure: supraesophageal.

Labial or subcerebral commissure: a primitive ganglionic ring around oesophagus between cerebral ganglia, anterior to pleural and pedal connectives.

Pedal or parapedal commissure: suboesophageal.

Visceral commissure or visceral ganglionic nerve-ring: between pleural ganglia, through parietal ganglia (or right subintestinal and left super-intestinal ganglia) and abdominal ganglion(s); see dialyneury, euthyneury, orthoneury, streptoneury and zygoneury.

Connective: right or left nerve connection between ganglia of different names, on the same side or along the twisted (streptoneurous) visceral commissure.

Abdominal connective: part of visceral ring between parietal (supra-intestinal or subintestinal) and abdominal ganglia.

Buccal connective: from cerebral ganglia or labial commissure to buccal ganglia; *syn.* cerebrobuccal, buccocerebral, or stomatogastric connective.

Cerebro-connective: see (buccal, pedal and pleural) connective.

Infra-intestinal connective: see (subintestinal) connective.
Parietal or pallial connective: from pleural to parietal ganglia; *syn.* pleuroparietal connective and pleuropallial.
Pedal connective: from cerebral to pedal ganglia; *syn.* cerebropedal connective.
Pleural connective: from cerebral to pleural ganglia; *syn.* cerebropleural connective; see dystenoid, epiarthroid and hypoarthroid.
Pleuroparietal or pleuropallial: see (parietal) connective.
Pleuropedal connective; from pleural to pedal ganglia; see epiarthroid and hypoarthroid.
Stomatogastric connective: see (buccal) connective.
Subintestinal connective: (streptoneury) from left pleural to subintestinal ganglia; *syn.* right visceral connective or right part of visceral commissure.
Super-intestinal connective: (streptoneury) from right pleural to subintestinal ganglia; *syn.* left visceral connective or left part of visceral commissure.
Zygo-connective: (zygoneury) from pleural ganglion to same side of visceral commissure.

Copulatory pouch (poche copulatrice, Guiart, 1900): spermatheca.

Crop: swelling (often temporary) of oesophagus commonly for the storage of food: (1) continuous with stomach, (2) demarcated by cephalic aorta, or (3) just behind buccal bulb; see also pharynx (of Leiblein).

Crypt: used for patches of glandular cells.

Cryptophallic: withdrawing penis into body or sheath (as in Pulmonata).

Crystalline style: see style.

Crystal sac: (Neritidae) a sac on uterus.

Ctenidium (ctenidial): one of primitively paired (zygobranch) branchiae in mantle cavity (associated with hypobranchial gland and osphradium); only left (azygobranch) ctenidium commonly retained; usually prosobranch (in front of heart) but see also opisthobranch (behind); *syn.* true branchia, as contrasted with pseudobranch.

Cusp or **cone:** see radula.

Dart or **dartus:** (Pulmonata) horny or calcareous (gypsobelum) sexual stimulator; specifically a belum formed on female organs (Pilsbry, 1894); but also a penial dart (see penis), pugio or stylet, or one formed in a male dart–apparatus; *syn.* spiculum amoris. A haplostyle is a simple, conical dart; a dispathostyle has two longitudinal blades; a tetraspathostyle has four; and a heterospathostyle has four split blades.

Dart apparatus: all structures accessory to dart (other than penial dart).
Atrial sac of dart apparatus: see (atrial sac of) dart sac, and atrial (vagina).
Mucous glands of dart apparatus: see dart gland.
Sheath of dart apparatus: (*Cepolis*, etc.) thin membrane which surrounds dart apparatus and may be homologous to distal dart-gland of other Cepolinae; often divided into two parts by a partition; *syn.* dart sheath.

Dart gland: glandular organ(s) associated with dart.
Distal dart gland: dart gland on apex of a. sac; (*Cepolis*, etc.) the glands of the dart sheath.
Duct of dart gland: drainage tube.
Proximal dart gland: (Cepolinae) secondary gland, developed as a swelling of the duct of the distal dart gland.

Dart papilla: that through which dart is extruded; but (dart papilla) also any stimulator developed in penis.
Sac of dart papilla: capsule around dart papilla.

Dart sac: capsule which contains and usually secretes dart; *syn.* stylophore.
Atrial sac or vestibule of dart sac: vestibular sac of dart apparatus, opening into atrium or vagina.

Dart sheath: see (sheath of) dart apparatus.
Deferent canal or **vas:** see vas (deferens); also testicular duct.
Dextral: right; used for normal snails in which mantle cavity and pallial complex are mainly on the left side, and the genital opening(s) on the right side; see left and right (organs), hyperstrophy and sinistral.
Diaphragm: partition; specifically the muscular one between the mantle cavity (or lung) and the haemocoele; the "floor" of the lung.
Penial diaphragm: see penis.
Dialyneury (dialyneurous): streptoneury, with an inosculation (connection) between pallial nerves from: (left dialyneury) left pleural and supra-intestinal ganglia: or (right dialyneury) right pleural and subintestinal ganglia.
Diaulos (diaulic): hermaphroditic gonaduct which divides into oviduct and spermiduct, but often used to mean a ditremate one.
Digestive system: mouth, buccal bulb with salivary glands, oesophagus, stomach, pylorus and liver, intestine, rectum or hindgut, and anus. See Carriker (1947).
Digonoporous: ditremate.
Dispathostyle: dart with two longitudinal blades.
Ditremate: (mollusks) with two genital apertures (see genital) in one animal.
Diverticle (diverticular) or diverticulum: any lateral or basal pouch or branch.
Docoglossate: (Docoglossa) with few elongate, brittle and brown teeth in narrow radula.
Dorsad: dorsally.
Dorsal: (dorso-): towards back (dorsum), usually of foot or head.
Dorsocaudal nerve: see (caudal) nerve.
Ductus receptaculo-uterinus (Ihering): an artery.
Dystenoid: with quite long pleural and pedal connectives (see connective).

Ectocone (ectoconal): see radula.
Egg: egg cell (ovum) with (or without) its envelopes (albumen, shell, etc.). See oviparity, ovoviviparity and viviparity; also ovary.
Egg gland: see albumen, nidamental, sole (punch) thalamus, uterus, vitellus.
Egg sac: (Helicinidae) compartment at base of ovary.
Elasmognath: see jaw.
Elevator: muscle which pulls upwards or dorsad.
Endocone: see radula (entocone).
Entero-aortic nerve: see nerve.
Enteron (enteric): strictly the endodermal midgut, but loosely applied to "intestine."
Entocone: see radula.
Epididymis: convoluted ducts from testis; ovisperm duct.
Epiphallus (epiphallic or epiphallar): (Pilsbry, 1894) apical chamber of penis which usually develops spermatophore and is not eversible; strictly the penial epiphallus; see (epiphallar) retractor. Vas epiphallus: a swelling of vas.
Epiphallus branch of penis: see penis.
Epiphallus caecum or calc sac: epiphallic blind pouch or appendage; see epiphallic flagellum or epiphallic diverticulum.
Epiphallus corona: (Microcystinae) epiphallic enlargement near penial end.
Epiphallus diverticulum or lobe: any lateral pouch; either proximal epiphallic diverticulum near penial end, or retractor epiphallic diverticulum at insertion of retractor muscle.
Epiphallus flagellum: portion of epiphallus above entrance of vas; usually secretes "tail" of spermatophore.
Epiphallus gland: any gland or gland zone emptying into epiphallus.
Epiphallus opening, orifice or pore (EP): that into penis proper.

Epiphallus proper: exclusive of its flagellum; usually develops "head" of spermatophore.

Epiphallus retractor caecum: see epiphallus diverticulum.

Epiphallus sheath: membranous or muscular sac around epiphallus, if distinct from penial sheath.

Epipodium (epipodial): an expansion around sides of foot, often with epipodial tentacles or lobes; see parapodium.

Esophagus (esophageal): tube between buccal bulb and stomach, and sometimes locally swollen into a crop; divided into pro-esophagus and post-esophagus by Carriker (1947); see (esophagus) nerve and oesophagus.

Euthyneury (euthyneurous): condition of visceral ganglionic ring when not twisted (see streptoneury); secondary in gastropods, supposedly due to detorsion (opisthobranchs), or (Pulmonata) because of shortened connectives (but see zygosis).

Evaginate: to unsheathe (acrecbolicly).

Evert: to turn inside out.

Excretory organs: see kidney, pericardium and ureter; *syn.* nephridial and renal organs.

Exophallic: with permanently extruded verge or penis.

Eye (optic or ocular): sense organ for reception of light and formation of an image; usually on head (cephalic eye); see (optic) nerve and (ommatophoral) retractor.

Eye tentacle or ommatophore: eye peduncle or stalk; (Stylommatophora) one of upper cephalic pair, with eye at tip, a pleurecbolic introvert (see introvert).

Pallial eye: eye on outside of mantle *(Onchidium)* or near osphradium.

Ganglion (ganglia; ganglionic): a mass of nerve cell bodies from which nerve fibers originate.

Buccal ganglion: paired ganglia on lower side of oesophagus near buccal bulb; with buccal commissure; its connectives are (cerebro-) buccal; see (buccal) nerves. *Syn.* stomatogastric ganglion.

Cerebral ganglion: paired ganglia or bilobed ganglion above oesophagus; often with buccal or labial, cerebral (mesocerebral), pedal and pleural (metacerebral), and tentacular (protocerebral) gyri or lobes; with cerebral and labial commissures; its connectives are buccal, pedal and pleural; see acoustic, frontal, labial, nuchal, optic, penial, subcerebral and tentacular nerves. *Syn.* supra-oesophageal ganglion.

Ctenidial ganglion: see (osphradial) ganglion.

Ganglionic nerve-plexus: *(Lymnaea)* dorsogastric and ventrogastric around liver ducts; connecting with gastric (buccal), intestinal (abdominal) and genital; see Carriker (1947).

Ganglionic nerve-rings: four circumesophageal ones from cerebral ganglia, *i.e.,* the labial commissure and the buccal, pedal and pleural nerve-rings; the last includes the visceral nerve-ring or loop, which forms a commissure between the pleural ganglia.

Infra-intestinal ganglion: see (subintestinal) ganglion.

Osphradial ganglion: ganglion near osphradium, on left (in streptoneury) and/or right (in Pulmonata) pallial nerve(s); its nerves are branchial or ctenidial, osphradial, etc. *Syn.* (but sometimes distinct) branchial and ctenidial ganglia.

Pallial or parietal ganglion: preferable to parietal, which apparently is becoming the more general usage.

Pallio-abdominal ganglion: formed by fusion of abdominal ganglion. with both parietal ganglia; *syn.* parieto-abdominal or abdominal ganglion.

Right parietal ganglion: fusion of abdominal ganglion with right parietal ganglion.

Left parietal ganglion: fusion of abdominal ganglion with left parietal ganglion.

Parietal or pallial ganglion: (Pulmonata) paired ganglia on visceral loop between pleural and abdominal ganglia, or fused with last; its connectives are (pleuro-) parietal and abdominal; its nerves: left and right pallial. *Syn.* visceral ganglion, but the left (visceral or superintestinal) ganglion of streptoneury is replaced by the right (visceral or parietal) ganglion in euthyneury, and vice versa; see also zygosis.

Pedal ganglion: lowest (ventral) paired ganglia or bilobed ganglion below oesophagus; sometimes elongate as pedal cords; with pedal commissure (often with additional parapedal ones); its connectives are (cerebro-) pedal and pleuropedal; its nerves: pedal and penial.

Pleural ganglion: paired ganglia between cerebral ganglia and parietal (supra-intestinal or sub-intestinal) ganglia; with ganglionic visceral commissure; its connectives are (cerebro-) pleural, parietal (subintestinal or supra-intestinal), and pleuropedal; its nerve (primitively) the pallial, so rarely called pallial ganglion.

Stomatogastric ganglion: now usually called buccal ganglion.

Subintestinal ganglion: in streptoneury, the right (visceral) ganglion, which is connected to left pleural ganglion along visceral loop; its connectives are (pleuro-) subintestinal and abdominal; its nerves (especially in zygoneury) the right pallial. *Syn.* infra-intestinal ganglion.

Subesophageal ganglia: pedal and pleural ganglia; (Pulmonata); also parietal and abdominal ganglia; (in position) buccal ganglia as well.

Super-intestinal ganglion: in streptoneury, the left (visceral) ganglion, which is connected with the right pleural ganglion along the visceral loop; its connectives are (pleuro-) supra-intestinal and abdominal; its nerves (especially in zygoneury) the left pallial; *syn.* supra-intestinal ganglion.

Super-esophageal ganglion: cerebral ganglion.

Visceral ganglion: any ganglion on visceral loop, *i.e.,* the subintestinal (right visceral) or left parietal (left visceral), the supra-intestinal (left visceral) or right parietal (right visceral), and the abdominal (posterior visceral) ganglion.

Gastric: pertaining to the stomach; (see stomach) and (ganglia) nerve.

Genital or **generative:** pertaining to reproduction.

Genital aperture or gonopore: any external reproductive opening; a monotremate snail has one, which may be male, female or hermaphrodite; a ditremate one has two, which may be male and female, or a female may have separate oviducal and provaginal, spermathecal or vaginal openings; and a triaulic hermaphrodite may have three.

Genital bladder: spermatheca.

Genital vestibule: see atrium.

Genitalia (plural) or genitals: include all reproductive organs; see gonad and gonaduct; also monaulos, diaulos and triaulos.

Gill: organ for breathing under water; see branchia and ctenidium.

Gizzard: see stomach, which is largely a gizzard, but so is man's.

Gland (glandular): used (often loosely) for almost any organ with glandular cells; see adrectal, albumen, anal, atrium, buccal, caudal, dart, epiphallus, hypobranchial, mantle, nidamental, oesophagus, oviduct, pedal, penis, prostate, salivary, sole, suprapedal, thalamus, uterus, vagina and vitellus.

Glans: Latin for gland, but also used for penis or verge.

Gonad (gonadic or gonadial): organ in which ova and/or sperm-cells develop; see ovary (female), ovotestis (hermaphrodite) and testis (male).

Gonaduct (gonaducal) or gonad duct: any canal or passage from gonad to outside; see oviduct (female), ovisperm duct, carrefour, spermoviduct and atrium (hermaphrodite), and spermiduct (male).

Apical gonaduct or primary azygogonaduct: part, in apical viscera, supposedly homologous with right primary gonaduct and uroduct; *syn.* hepatic gonaduct.
Primary gonoduct: supposedly the duct from the gonad to the uroduct.
Secondary or pleuropedal gonoduct: supposedly added to apical gonaduct from pallial cavity, which it parallels. Pleural or pleuropedal gonaduct.

Gonopore: see genital (aperture).

Haemocoele, hemocele, or **hemocoel:** large blood-sinus; (Stylommatophora) (Pulmonata) specifically the body cavity or pleuropedal sinus, which may contain buccal bulb, salivary glands and oesophagus, ganglionic nerve-rings, secondary gonaducts, and free retractors.

Haplostyle: simple, conical dart.

Head (cephalic): anterior end of animal, often not demarcated dorsally from foot (Propodium); region around cephalic tentacles, eyes and mouth.
Mid-dorsal sulcus of head: groove(s) down middle of back.

Heart (cardiac): blood-pumping organ in pericardium, usually near kidney; with one (primitively two) auricle or atrium, which receives veins from ctenidium or lung, and opens (past valves) into a ventricle, that pumps blood out through aorta and/or arteries.

Hemocoele: preferable to haemocoele.

Hepatic: pertaining to the liver (see liver).
Hepatic or apical viscera: see viscera.

Hepatopancreas: see liver.

Hermaphrodite or **hermaphroditic:** with both sexes (male and female) combined in one snail; *syn.* monoecious.
Hermaphroditic duct: (Pulmonata) ovisperm duct, from ovotestis to carrefour.
Hermaphroditic gland: ovotestis.

Heterospathostyle: dart with four bipartite blades (eight in all).

Heterurethrous: with kidney and ureter transverse, as in Succineidae.

Hindgut: part of digestive canal derived from proctodaeum; (Pulmonata) includes the intestine; but commonly applied to last part (rectum), which usually is along right (columellar) side of pallial cavity, but may pass through pericardium in zygobranchs.

Hyperphallus (hyperphallic): (H.B. Baker, 1925b) vergic sac of penis.

Hyperpolyandry: males larger than females. Hyperpolygyny: *vice versa.*

Hyperstrophy: sinistral animal in dextral shell (*e.g.*, "ultradextral" Planorbidae), or *vice versa (e.g., Lanistes).*

Hypoarthroid: with pleuropedal connectives (see connective) shorter than (cerebro-) pleural ones.

Hypobranchial gland: pallial mucous gland, often near ctenidium; right one (parabrachium) usually vestigial or absent.

Infra-intestinal: see (subintestinal) ganglion and connective.

Intestine (intestinal): tube from apical end of stomach (or pylorus) to rectum; often twisted into S-loops, which consist of (1) a descending limb (pro-intestine) to near posterior lung-wall, (2) an ascending limb (mid-intestine) and (3) a 2nd descending limb (post-intestine); last two limbs usually imbedded in liver posterior lung-wall (not in some small snails) or shortened to a transverse limb across (some predaceous snails).

Introversible: capable of introversion, which is the act of introverting.

Introvert: (verb) to turn outside in (opposite of evert), so exterior of organ becomes lining of cavity; (noun) an introversible organ; see Pelseneer (1906), p. 87, fig. 72.
Acrecbolic introvert: one that everts its apex first, like proboscis sheath of some gas-

tropods (*e.g., Urosalpinx,* see Carriker, 1943), which is also pleurembolic. (Evagination is intrinsically acrecbolic).

Acrembolic introvert: one that introverts its apex first; see pleurecbolic.

Limited introvert: organ not fully introversible, like a penis with a verge, or a proboscis and its acrecbolic sheath.

Pleurecbolic introvert: one that everts its sides first, like eye tentacles, or proboscis of some gastropods *(e.g., Cypraea);* these are also acrembolic.

Pleurembolic introvert: one that introverts its sides first; see acrecbolic.

Invaginate: to become sheathed, often by retraction into an introvert, like a verge in a pleurecbolic penis, or a proboscis in an acrecbolic sheath.

Jaw (gnathic): (Pulmonata) horny thickening(s) behind upper lip above mouth; *syn.* dorsal sclerite; (most gastropods) a right or left, lateral mandible.

Dorsal or superior jaw: upper jaw of Pulmonata; *syn.* median jaw.

Elasmognathous: with a recurved plate on back of jaw (Succineidae).

Holognathous: with jaw in one piece; not elasmognathous.

Jawless: agnathous.

Lateral or accessory jaw: horny thickening either side of mouth. With jaw of separate plates: polyplacognathous; the most primitive (or vestigial) jaw, with plates that usually overlap from center towards outside.

With plaited or soldered jaw: stegognathous, with plates joined narrowly; but goniognathous if plaits converge below.

With ribbed jaw: odontognathous, with fused plates thickened at edges.

With smooth jaw: oxygnathous; but leiognathous if without median point.

With striate jaw: aulacognathous.

With thick jaw: pycnognathous.

Kidney (renal): excretory organ, usually developed on left uroduct, normally against apical wall of lung; *syn.* nephridium, organ of Bojanus, papillate sac of Heller, and urocoele; see also heterurethrous, orthurethrous and sigmurethrous.

Base of k.: side along posterior wall of mantle cavity.

Duct of k.: ureter.

Length of kidney: expressed in terms of its base or length of pericardium.

Orifice of kidney: opening into ureter.

Pericardial or renopericardial pore or canal of kidney: opening between pericardium and kidney.

Labial: pertaining to lips; see commissure (JCM) and nerve.

Labial glands: mucous glands in propodial groove.

Labial gyrus or lobe: lobe of cerebral ganglion (see ganglion) at origin of labial commissure.

Labial lobe: projection at corner of mouth.

Labial palp: long labial lobe, as in *Euglandina.*

Labial veil: see buccal (veil).

Labrum: palatal edge of shell or mantle collar.

Laterad: laterally.

Lateral (latero-): towards or on either side of center; see radula.

Left organ: one actually on left side of dextral animal, but on right side of a sinistral one. In streptoneury, the super-intestinal ganglion, although it corresponds to the right parietal or pallial ganglion. A mantle (pallial) organ towards periphery from heart or rectum, although, when mantle cavity is reversed by torsion (as in prosobranchs), its best developed and left organs would be its originally right ones.

Levators: muscles which pull craniad; (mollusks) see elevators.

Liver (hepatic): principal digestive organ, a sort of liver-pancreas-intestine (duodenum), forming the bulk of the apical viscera; *syn.* hepatopancreas, pancreas, and gastric gland.

Duct of liver: from each lobe of liver to pylorus.

Lobe of liver: either of two main divisions: the apical posterior or right (morphologically left?) one, and the basal, anterior or left (morphologically right?) one.

Locomotion (locomotor): snails usually swim by means of microscopic cilia, in water or on a strip of secreted mucus, but they also utilize muscular contractions of the sole (see sole), usually up and down, but rarely sidewise (like a snake).

Lung (pulmonary): mantle cavity (often increased secondarily), when specialized as a pulmonary sac for air breathing; especially its external wall.

Lung aperture: external opening of lung; *syn.* pneumostome, pneumopore.

Lung venation: pulmonary veins.

Major lung vein: the principal vein, which empties into auricle of heart, and its visible tributaries.

Minor lung vein the tributaries of the principal vein are often indistinct or apparently lacking, especially in small species.

Lung wall: specifically, the external side (LW) or lung proper.

Anterior lung wall: that between mantle collar and diaphragm or "neck"; *syn.* velum (F.C. Baker, 1911).

Apical lung wall: usually called posterior lung wall.

External lung wall: the lung proper.

Internal or lower lung wall: diaphragm.

Posterior lung wall: apical side, between lung wall proper and diaphragm; usually at about the level of the posterior (apical) wall of haemocoele (body cavity), the cephalic aorta, and the constriction between the albumen gland and the uterus or spermoviduct; see (apical) viscera.

Mammillary: breast-shaped or nipple-shaped (see papilla).

Mandible: jaw; (Pulmonata) (most other gastropods) paired having jaw each side of mouth.

Mantle (pallial): that portion of covering (skin) of a mollusk which normally is inside of and secretes (and/or dissolves) the shell; it covers apical visceral sac, forms mantle collar (which forms the shell), and lines mantle cavity; *syn.* pallium.

Mantle cavity: that inside m. wall or "free" fold of mantle, (pulmonates) lung.

Mantle collar: thickening of apertural or peristomal edge of mantle; forms shell and secretes its "epidermal" (outer) and prismatic (middle) layers; *syn.* muscular collar of the velum (F.C. Baker, 1911).

Mantle gland: any of mucous glands of mantle collar, which often encroach on lung surface; see anal (gland).

Mantle lappet: (Pulmonata) lobe or flap of mantle collar, which extends towards or along "neck" or foot; *syn.* body lobe and inferior pallial lobe; see shell lap and lobe.

Anterior left or angulopalatal mantle lappet: usually anterior to pneumostome on same (right) side of animal.

Left or palatal mantle lappet: continuous from pneumostome over "neck" to left side of animal; combines the other two.

Posterior left or basopalatal mantle lappet: on left side.

Mantle retractor; see retractor.

Mantle siphon: see siphon.

Mantle wall: see lung wall, but anterior end is commonly open.

Marginal: towards outer edge; see radula.

Medial (medio- or meso-): towards middle plane of animal.
Mentum (mental): fleshy crescent between opening of suprapedal gland and sole.
Mesocone: see radula.
Metapodium: highbrow name for tail; see also caudal and operculum.
Mid-: middle; see caudal, head, and intestine.
Midgut: true endodermal enteron; (Pulmonata) apparently only the pylorus; but in many gastropods includes most of stomach, intestine and rectum.
Monaulos (monaulic): undivided gonaduct, *e.g.*, one not divided into oviduct and spermiduct, but often used to mean a monotremate one.
Monoecious: hermaphroditic.
Monotremate: (mollusks) with only one genital (aperture).
Mouth (oral or stomatic): usually just ventral to anterior end; commonly with a hard jaw(s), which may work against radula. The "true" mouth of some snails is at the end of a proboscis; for "false" mouth, see rhynchostome
Mouth (oral) cavity: that in front of radular cartilages.
Mucus (mucous or mucilaginous): a viscid liquid or slime; land snails actually swim along a trail of mucus.
Mucous gland: although mucous gland cells are all over body, mucous gland is applied loosely to almost any patch, crypt or blind pouch, in which these cells are abundant; see gland.
Muscle (muscular): for "free" muscles, see protractor and retractor.

Nerve (nervous or neural): slender, peripheral strand of nervous system, mainly containing n. fibers but (mollusks) often with nerve cells; see also nerve cord. In the following list, mainly some of the commoner usages in Pulmonata, the 2nd name (in parentheses) gives the usual ganglionic origin. Since many nerves have both *sensu lato* and *sensu stricto* meanings, they are distinguished as main nerves (nerve or nerves; *sensu lato*), which often arise directly from the ganglia, and the minor branches or rami (ramus or rami; *sensu stricto*).
Abdominal nerve: any from abdominal ganglion; see especially anal, aortic, caudal and intestinal nerves.
Acoustic (cerebral) nerve: to otocyst, often along cerebropedal connectives; *syn.* auditory, otocystic and statocystic.
Anal (abdominal) or right lateral nerve: unpaired, towards rectum and often supplying anus; *syn.* media] (internal) pallial, or mediopallial.
Anal rami: *(Lymnaea)* from right pallial nerve.
Aortic (abdominal) or left lateral nerve: unpaired, along cephalic aorta to left bodywall; see also caudal nerve.
Aortic rami: see cardiac rami.
Buccal nerve: any from buccal ganglion, or nearby connective; *syn.* pharyngeal nerve.
Anterior buccal nerve: any from anterior side of buccal ganglion; may include gastric, salivary and/or anterior esophageal nerves or rami; *syn.* 1st buccal, dorsobuccal.
Deep buccal nerve: to odontophore; *syn.* odontophoral, radular or post-buccal.
Lateral buccal nerve: from lateral side of buccal ganglion; may include lateral (laterobuccal), ventral (ventro-buccal) and deep buccal; *syn.* 2nd buccal.
Posterior buccal nerve: median and/or paired, from posterior side of buccal ganglion; usually deep buccal, but may include gastric and salivary nerves or rami; *syn.* 3rd buccal nerve.
Buccal retractor nerve: to buccal retractor; origin from pleural connective or ganglion, visceral loop or *(Lymnaea)* buccal connective; *syn.* bucco-retractor nerve.
Cardiac (abdominal) rami: to pericardium, kidney and adjacent vessels, commonly

from intestinal or carditogenital nerve.

Carditogenital (abdominal) nerve: unpaired, with genital, cardiac and other rami; often combined in intestinal nerve; see also entero-aortic nerve.

Caudal (abdominal) nerve: unpaired, goes to root of tail, tail retractors and adjacent skin and mantle; *syn.* columellar or dorsocaudal nerve, and often includes aortic and suprapedal nerves.

Cerebral nerve: any from cerebral ganglion; see acoustic, frontal, labial, nuchal, optic, penial, subcerebral and tentacular nerves.

Columellar nerve: see caudal and tentacular retractor nerves.

Columellar rami: from caudal, pallial and/or intestinal nerves.

Ctenidial rami: to ctenidium, from osphradial ganglion or pallial nerve.

Entero-aortic (abdominal) nerve: unpaired, along cephalic aorta; includes parts of aortic and (not carditogenital) intestinal nerves.

Esophageal (buccal) nerve: see gastric nerve.

Esophageal rami: to esophagus.

Anterior esophageal nerve or ramus: to anterior end of esophagus, often from anterior buccal nerve; *syn.* anterior gastric or pro-esophageal.

Posterior esophageal nerve: see gastric nerve. Posterior esophageal rami: *syn.* post-esophageal.

Frontal (cerebral) nerve: one to three nerves to around base of ommatophore or cephalic tentacle and sides of head; sometimes (fronto-labial nerve: *Lymnaea*) with upper labial ramus; *syn.* (or including) lateral (external) and media] (internal) peritentacular nerves. and cephalic cutaneous nerve (Schmalz, 1914).

Gastric (buccal) nerve: posteriad along esophagus, with esophagus, salivary, gastric and intestinal rami; *syn.* posterior gastric or posterior esophageal. Gastric (abdominal) ramus: see intestinal nerve. See also (gastric) ganglionic (nerve-plexus).

Anterior gastric nerve (Schmalz): see anterior esophageal nerve.

Posterior gastric nerve (Schmalz): see gastric nerve.

Genital (abdominal) nerve: see intestinal nerve. Genital ramus: to pleural and apical genitalia, with gonadic branch; usually from intestinal or carditogenital nerve.

Intestinal (abdominal) or sub-intestinal nerve: unpaired; the principal (a.) visceral nerve; it may give off aortic, cardiac, columellar, gastric, genital and intestinal rami, or these may be divided between entero-aortic and carditogenital nerves; *syn.* genital, sub-intestinal or splanchnic nerve.

Intestinal (abdominal and buccal) rami: also from gastric nerve. See (gastric) ganglionic (nerve-plexus).

Labial (cerebral) or lip nerve: to corners of lips: *syn.* lateral labial or rostral nerve; see also (labial) commissure, and subcerebral, frontal (fronto-llabial) and nuchal (nucho-labial) nerves.

Lower labial nerve or ramus: to ventral (or posterior) lip and (often) anterior end of radula; *(Lymnaea)* with nuchal rami; *syn.* inferior, posterior or lateral (external or Schmalz) labial or ventro-labial nerves.

Palpo-labial nerve: a lower labial combined with a lower tentacular nerve; *syn.* facial nerve (Böhmig) or middle (median of Schmalz) labial nerve.

Upper labial nerve or ramus: to dorsal (or anterior) lip; *syn.* anterior, superior, media] (internal of Schmalz) labial or dorso-labial nerve; see frontal and nuchal nerves.

Lateral (abdominal) nerves.

Left lateral nerve: see anal nerve.

Right lateral nerve: see aortic end caudal nerves.

Mantle nerves: see pallial and anal nerves.

Nerve cord: an elongate ganglion (see pedal ganglion) or a nerve containing many nerve cells.

Nerve plexus: see ganglion (nerve plexus).
Nervous system: ganglionic nerve-rings with their ganglia, commissures and connectives, the (peripheral) nerves and their rami, and the sense organs.
Nuchal (cerebral) nerve: to anterior dorsum of foot and anterior lung-wall; sometimes (nucholabial nerve) combined with labial nerves; *syn.* dorsal peritentacular or velar nerve.
Odontophoral (buccal) nerve: see (deep) buccal nerve.
Oesophageal nerve: see esophageal nerve.
Olfactory (cerebral) nerve: see (inferior) tentacular and ommatophoral nerves.
Ommatophoral (cerebral) nerve: to eye tentacle; *syn.* superior tentacular, oculotentacular or olfactory (Schmalz) nerve.
Optic (cerebral) nerve: to eye, often on or in ommatophoral or tentacular nerve; *syn.* eye or ocular nerve.
Osphradial nerve: to osphradium; see (osphradial) ganglion.
Otocystic (cerebral) nerve: see acoustic nerve.
Pallial (abdominal) nerve: (Pulmonata) preferably restricted to nerves from pallial or parietal ganglion.
Medio-pallial nerve: see anal nerve.
Ventro-pallial or suprapedal nerve: runs posteriad, to mantle and suprapedal gland under columellar retractors; often a ramus of intestinal nerve.
Pallial (parietal) nerve: any to mantle-fold; primitively from pleural ganglion and/or (especially in dialyneury and zygoneury) subintestinal or super-intestinal ganglia; (Pulmonata) preferably limited to those from pallial or parietal ganglion.
Anterior right pallial nerve: *(Lymnaea)* inosculates with anal nerve: see medial ramus of right pallial nerve.
Left pallial nerve: one or more to left (lateral) side of mantle fold or lung.
Left pallail cutaneous nerve (Schmalz): to basopalatal part of mantle and mantle collar; often a branch of left pallial nerve.
Right pallial nerve: one or more (see anterior right pallial) to middle and right side of mantle fold or lung, and to osphradium, when present; often with lateral (external of Schmalz) or middle pallial ramus, and medial (internal of Schmalz) or right pallial ramus.
Palliocolumellar (pleural) nerve: *(Hendersonia)* with columellar rami.
Palpolabial nerve: see labial nerves.
Parietal nerve: see pallial nerve.
Pedal (pedal) nerves: (Pulmonata) commonly in three layers: (1) lateral, (2) ventral, and (3) arterial pedal nerves.
Arterial pedal nerves: anterior and posterior arterial pedal nerves to arteries of foot and suprapedal gland.
Lateral (external) or cutaneous pedal nerves: laterad to sides of foot; commonly three or in three groups.
Anterior lateral pedal nerve: running obliquely anteriad; *syn.* 1st cutaneous pedial or superior cervical nerve.
Middle lateral pedal nerve: running laterad; *syn.* 2nd cutaneous, lateral or mesolateral pedal or inferior cervical nerve.
Posterior lateral pedal nerve: running obliquely caudad; *syn.* 3rd cutaneous or median posterior pedal nerve.
Ventral pedal nerves: obliquely ventrad towards sole; *syn.* sole nerves or nerves to pedal muscles; numerous, but often divisible into three groups:
Anterior ventral pedal nerves: *syn.* superior pedal or anterior sole nerves.
Middle ventral pedal nerves: *syn.* lateral sole or central or mesoventral pedal nerves.
Posterior ventral pedal nerves: *syn.* posterior sole, or inferior or posteroventral pedal

nerves.

Penial (right cerebral) nerve: usually to penial apex, which also may have a special vergic nerve; sometimes reduced or wanting, especially when penis is near middle of foot *(Retinella)*.

Penial (right pedal) nerve: usually to atrium and base of penis; often united with anterior lateral pedal nerve.

Peritentacular nerves: see frontal and nuchal nerves.

Pleural nerve: any from pleural ganglion; see pallial and tentacular retractor nerve.

Radular nerve: see (deep) buccal nerve.

Retractor nerves or rami: see columellar rami, and buccal and tentacular retractor nerves.

Rhinophoral (cerebral) nerve: see (lower) tentacular nerve.

Salivary (buccal) nerves or rami: to salivary glands; usually rami of anterior or posterior buccal nerve or gastric nerve.

Sole nerves: see (ventral) pedal nerves.

Splanchnic nerve (Carriker, 1947): nice (in best study yet) but too late; see intestinal or sub-intestinal nerve.

Statocystic nerve: see acoustic nerve.

Stomachal rami: see gastric and intestinal nerves.

Subcerebral (cerebral) nerve: taking same route as labial commissure, to floor of body cavity; *syn.* cerebral artery nerve (Schmalz).

Subintestinal (abdominal) nerve: (Pulmonata only) perhaps a better term than intestinal, which see; *syn.* splanchnic nerve.

Suprapedal (abdominal) nerve: see pallial (abdominal) nerves.

Tentacular (cerebral) nerve: to a cephalic tentacle.

Lower or inferior tentacular nerve or ramus: to lower cephalic tentacle (when present); *syn.* rhinophoral or olfactory nerve; see also (palpo-) labial nerve.

Upper or superior tentacular nerve: see ommatophoral nerve.

Tentacular retractor (pleural) nerve: mainly to tentacular retractor; *syn.* columellar muscle nerve (Schmalz) and tentaculoretractor nerve.

Velar (cerebral) ramus: see nuchal nerve.

Vergic (right cerebral) nerve: to vergic or vergic sac of penis; *syn.* hyperphallic nerve; see also penial (cerebral) nerve.

Nephridium: see kidney.

Nephrostome: opening of primary ureter or uroduct.

Nidamental (?) or muciparous gland: (Basommatophora) bulbous diverticulum on oviduct or uterus; *syn.* second accessory albuminiparous gland (F.C. Baker, 1911), oviducal diverticulum (H.B. Baker, 1925b), prebulbar gland, or muciparous gland.

Nuchal: pertaining to "nape" or "neck" of foot, just in front of visceral stalk; see (nuchal) nerve.

Nuchal cavity: vestigial mantle-cavity (Docoglossa).

Ocular: see optic.

Oculotentacular: see ommatophore.

Odontophore (odontophoral): loosely applied to accessory radular structures, including "cushion" or rotella; see (odontophoral) nerve and radula.

Oesophagus (oesophageal) or (better) **esophagus**: tube between buccal bulb and stomach; *syn.* gullet; see esophagus and (esophageal) nerves.

Oesophageal or circum-esophageal ring: any one of the four ganglionic nerve-rings (see ganglia) around oesophagus.

Oesophageal gland or caecum: (Prosobranchia) special gland, sometimes poisonous; (Stenoglossa) large gland 4 Leiblein, opening into oesophagus posterior to

pharynx of Leiblein.

Oesophageal sacs or pouches: (neritoids) caeca near anterior end of oesophagus.

Ommatophore (ommatophoral): eye peduncle; (Stylommatophora) one of the upper of two cephalic pairs; see nerve; *syn.* oculotentacle, superior tentacle.

Oncheiopodium: copulatory organ on foot; see verge.

Oötype: (neritoids): secondary gonaduct or uterus.

Operculum (opercular or operculigerous): "trap-door" which is secreted by tail and is attached to it; *syn.* opercle. Operculum spiral (when visible) usually reverses that of shell; *i.e.*, sinistral opercula go with dextral shells.

Accessory opercular organs (H.B. Baker, 1925c): sacs either side of operculum disc.

Opercular disc: platform which bears operculum and secretes its inner (ventral) veneer.

Opercular groove or sulcus: that which forms operculum's horny and calcareous "plates," and which adds to them successive boxes, separated by growth lamellae, or "ribs."

Opercular lobe: any tail process which bears opercular disc.

Opercular muscle: that inserted on operculum; it secretes the muscle "scar," which reverses any spiral of the operculum (*i.e.*, agrees with that of shell).

Opisthobranch: belonging to the Opisthobranchia; literally, with ctenidium behind (heart).

Optic: pertaining to eye; see (optic) nerve.

Oral: pertaining to mouth (see mouth).

Orthoneury (orthoneurous): (Helicinidae) streptoneury with reduction of the supraintestinal ganglion and its (left) part of visceral loop.

Orthurethrous: with ureter continuing kidney anteriad, although sometimes slightly recurved near its aperture.

Osphradium (osphradial): sense organ, receptor of chemical stimuli, near base of ctenidium; (Azygobranchia) specifically the left osphradium, since the right osphradium (parabranchia) is vestigial or wanting.

Otocyst (otocystic): small sac, often on dorsal surface of each pedal ganglion, with which stony otoliths, otoconia or statoliths are associated; mainly a sense organ of balance; *syn.* statocyst; see (acoustic) nerve.

Ovary (ovarian): the female gonad, which only develops ova or egg cells.

Ovarian duct: relatively slender duct from ovary.

Ovarian sac: egg sac on base of ovary.

Oviduct (oviducal): the female gonaduct; any channel through which only eggs pass; specifically the free oviduct; (Pulmonata) female passages commonly consisting of (1) the swollen uterus, which may be divided (Lymnaeidae) into (1a) slender pre-uterine part and (1b) uterus proper, and may receive (1c) a "nidamental" gland; (2) the postuterine oviduct, which may develop (2b) an oviducal gland; and (3) the vagina, which is the part (sometimes absent) below the entrance of the spermatheca (S). *Syn.* egg duct.

Apical or primary azygous oviduct: female a. gonaduct, which (neritoids) may consist of: (1) egg sac, (2) the slender ovarian duct, (3) the V-organ, sometimes with (3a) accessory spermatheca and (3b) peduncle, (4) the thalamus or fertilization (?) chamber, which opens into the uterus and may bear thalamic glands, (5) the connecting duct, (6) the provagina, which receives (6a) a dorsal (S) and (6b) a ventral spermatheca, and (7) provaginal aperture, into mantle cavity or hypobranchial gland. N.B. Parts 4, 5, and 6 are fused in many Helicinidae.

Free oviduct or oviduct proper: applied to post-uterine oviduct when uterus and spermiduct are not free (*i.e.*, are attached to each other).

Oviducal aperture: opening of a post-uterine oviduct that serves as an external geni-

tal (aperture).

Oviducal bulb or uterus proper: (Lymnaeidae, F.C. Baker, 1928) uterine swelling of oviduct; *syn.* vagina (F.C. Baker, 1900), first accessory albumen gland (F.C. Baker, 1911) and bulbar enlargement of oviduct (H.B. Baker, 1925b).

Oviducal diverticulum: (H.B. Baker, 1925b) an accessory sac on prebulbar oviduct; *syn.* secondary accessory albumen gland or "nidamental" gland (F.C. Baker, 1911); (Planorbidae) a sac on uterus (F.C. Baker, 1945).

Oviducal gland: a gland on postuterine oviduct; see also "nidamental gland."

Oviducal opening: opening of post-uterine or free oviduct.

Postbulbar or post-uterine oviduct: slender or free oviduct proper below oviducal bulb or uterus; *syn.* (F.C. Baker, 1911) vagina.

Prebulbar or pre-uterine oviduct: between carrefour and oviducal bulb or uterus proper.

Primary oviduct: (neritoids) female primary gonaduct, including egg sac, ovarian duct and (part of) V-organ.

Secondary oviduct: (neritoids) uterus or ootype, which may be divided (Neritidae) into a glandular portion and a crystal sac; (Pulmonata) see oviduct.

Oviducocoelomic funnel: (neritoids) vestige of primitive opening between pericardial cavity and primary oviduct, of which it indicates the lower end.

Oviparity (oviparous): when eggs are laid before developing snail becomes apparent.

Ovisperm duct: (Pulmonata) hermaphroditic duct between ovotestis and carrefour; often enlarged to form seminal vesicles (see semen); *syn.* epididymis and spermovarian duct.

Ovotestis: gonad which develops both ova and sperm cells, often in the same alveolus or acinus (chamber); composed of one to many alveoli, which often are grouped in fan-shaped or conical lobes, each with its own duct; usually embedded in apical lobe of liver; *syn.* hermaphrodite "gland," spermovarium and testis.

Ovoviviparity (ovoviviparous): viviparity, when eggs are laid in which developing snail has become apparent.

Ovum or **ovule:** the egg cell, which may develop a new animal, usually after fertilization; see also egg, which is a more inclusive term.

Palate (palatal): left portion of mantle collar, which corresponds to the free part of the shell peristome; (Pulmonata) beginning on right side near pneumostome, extending across "neck" and continuing posteriad along left side; see (left or palatal) mantle (lappet), shell (lap) and shell (lobe).

Pallio-abdominal: see ganglion and (abdominal) connective.

Pallium (pallial): the mantle; specifically the fold bounding the mantle cavity; see lung and mantle, and (pallial) nerve and siphon, and (parietal or pallial) connective and ganglion.

Pallial branchia or gill; may be either true ctenidium or an accessory pseudobranch.

Pallial complex: organs in external wall of mantle cavity; excretory (*e.g.*, kidney), circulatory (heart), respiratory (ctenidium), sensory (osphradium) and openings of (especially apical) gonaducts, ureter and even rectum (anus).

Pallial eye: *(Onchidium)* on dorsal tubercles; *(Cerithidea)* near osphradium.

Pallial lappet or lobe: superior, see shell (lobe), and inferior, see mantle (lappet).

Pallial tentacle: (Valvatidae) on mantle collar.

Palp: feeler, usually near mouth; see labial and tentacle.

Palpolabial nerve: see nerve.
Pancreas: see liver, and (pyloric caecum of) stomach.
Papilla (papillate or papillose): any nipple-shaped structures; see penis (papilla and verge).
Papillate sac of Heller: kidney.
Parabranchia (parabranchial): right osphradium, usually vestigial or absent.
Parapodium (parapodial): (Pteropoda) fin-like expansions of foot.
Parietal: side of mantle collar against penult whorl; see (right or parietal) mantle (lappet) and shell (lap and lobe), and (parietal or pallial) ganglion and connective.
Parietal angle: (Pulmonata) most salient angle of mantle collar near pneumostome.
Parieto-abdominal: see (pallio-abdominal) ganglion and (abdominal) connective.
Pedal: pertaining to foot; see sole (pore and pouch) and (pedal) commissure, connective, ganglion and nerve.
Pedal cord: longitudinal nerve-cord in foot; see (pedal) ganglion.
Pedal gland: suprapedal gland; see also caudal and labial (gland) and sole (pouch).
Pedal or peripodial groove: (land snails) longitudinal single or double groove on sides of foot; *syn.* parapodial groove.
Pedal tentacle: (Valvatidae) at anterior corners of foot.
Penis (penial; *plural* penes): male copulatory organ; *syn.* phallus; see also verge. (Pulmonata; and preferably in all gastropods; an introvert, which functions when everted, but usually is drawn and described when introverted; actually many of the peculiarities of the "cavity" disappear when its "lining" becomes the outside of the functioning penis. *Syn.* (?) muscular sheath (muskulöse Scheide) and accessory organ (akzessorisches Organ) (Hubendick, 1945). Used by F.C. Baker (1900) for (penis) vergic sac and (1928) for (penis) verge. See also atrium, epiphallus, verge, and (penis) nerve, protractor, retractor and vas.
Penial apex: end farthest from atrium; the tip when everted.
Penial appendix (appendical): (Pilsbry, 1894) a long, apical caecum; sometimes opening through an appendical papilla and/or into an appendical branch of penis.
Penial caecum: short blind pouch; usually apical, but shorter than penial appendix.
Penial complex: (F.C.B., 1933) penis; and accessory structures.
Penial dart, pugio or stylet: dart developed in penis, sometimes in penial dart sac and with penial dart gland.
Penial diaphragm or ring; (F.C. Baker, 1945) constriction between vergic and preputial sacs of penis.
Penial diverticulum: lateral or basal pouch on penis.
Penial epiphallic branch: branch of penis which receives epiphallus.
Penial flagellum: see penial appendix.
Penial gland: penial dart or stimulator gland; (Planorbidae) special "stimulator" gland, which opens into vergic sac of penis, but is on wall of preputial sac; *syn.* preputial gland.
Penial gland duct: duce of penial gland; *syn.* (F.C.Baker, 1945) duct of preputium.
Penial gland sulcus: continuation of penial gland duct.
Penial lobe: lateral or basal pouch, shorter than penial diverticulum.
Penial papilla: see penial verge and penial stimulator.
Penial pilaster (PP) or pillar: (Pilsbry, 1894) longitudinal fold.
Penial prepuce (preputial): p. sheath; see also atrium.
Penial p.-sac or preputial sac of penis: (H.B. Baker, 1925b) basal sac of penis, as distinguished from its vergic sac; *syn.* penis sac (F.C. Baker, 1900) and praeputium (F.C. Baker, 1928).
Penis proper: eversible portion, exclusive of epiphallus, branches, etc.
Penial retentor muscle: muscle band between epiphallus and penis or penial sheath;

often a continuation of (penial) retractor.

Penial sac: see preputial sac of penis.

Penial sheath: capsule around penis or penial complex, when distinct from muscular walls of penis; often mistaken for penis itself; *syn.* penial prepuce; used by Hubendick (1945) for walls of penis itself.

Penial stimulator or penial stimulator papilla: almost any projection that roughens surface (lining) of penis; *syn.* penial sarcobelum.

Penial verge (vergic): non-introversible organ through which epiphallus or vas enters penis; it forms apex of everted penis, and (Basommatophora) often functions as the true copulatory organ; a penis with a verge is a limited introvert. *Syn.* penial verge papilla, penial papilla, or penis (F.C. Baker, 1928; also Hubendick, 1945); see also verge.

Sac of penial verge: chamber of penis which surrounds verge or verge papilla; usually also eversible; *syn.* penial sac of verge, hyperphallus (H.B. Baker, 1925b), inner sheath of penis (Hubendick, 1945), or penis (F.C.Baker, 1900). Its gland (Planorbidae) is the penial gland.

Vergic papilla of penis: a small verge.

Penioviducal angle: between oviduct and penis; *syn.* atrial angle.

Pericardium (pericardial): membranous sac investing heart; (Mollusca, see Century Dictionary) the pericardial cavity which it encloses; so redundancy is sometimes wise.

Pericardial cavity or pericardium: a coelome (?), which opens into kidney through renopericardial pore or canal and (primitively) may join primary gonaduct (see oviducocoelomic).

Pericardial coelomoduct: see uroduct.

Pericardial gland: excretory gland, usually on outer wall of pericardial cavity, but sometimes on auricle of heart.

Pericardial membrane, pericardial sac or pericardium: that surrounding pericardial cavity.

Peripodial groove : longitudinal groove on each side of foot above sole; (Aulacopoda) a double groove; *syn.* pedal groove and parapodial groove.

Peristome (peristomal or peristomial): around mouth, either of snail or its shell; see basal, columellar, palatal and parietal.

Peritentacular nerve: see (frontal) and (nucal) nerves.

Phallus (phallic): penis; phallate, with penis.

Pharynx (pharyngeal): see buccal.

Pharyngeal cavity: buccal cavity, exclusive of odontophore.

Pharynx of Leiblein: (Stenoglossa) muscular crop just anterior to oesophageal nerve rings; see Carriker (1943).

Pilaster or **pillar:** any longitudinal fold, or pillar in bas-relief.

Pleural (of pleuron): pertaining to a (thoracic) lateral part; also marginal; see connective, ganglion, radula and viscera.

Pleural gyrus: lobe of cerebral ganglion nearest p. connective.

Pleural stalk: continuation of visceral stalk to apical viscera; it is almost surrounded by pallial cavity, and contains pleural viscera.

Pleurecbolic, pleurembolic: see introvert.

Pleuropallial: see (pallial) connective.

Pleuropedal: see connective and viscera.

Pneumostome (pneumostomal) or **pneumopore**: external opening of lung, often with a sphincter muscle to close it.

Pôche: French for pouch. Pôche semilunaire: crescentic pouch.

Post-: after; see oviduct and spermiduct; also intestine and esophagus.

Posteriad: posteriorly.

Posterior (postero-) : (gastropods) usually means towards apical viscera, but also means

towards tail (see caudal); see (posterior) lung-wall.

Praeputium or **prepuce** (preputial): see penis (sheath); (F.C. Baker, 1928) see penis (prepuce-sac); see also atrium.

Duct of praeputium (F.C. Baker, 1945): see penis (gland-duct).

Preputial gland: see penis (gland).

Pre- or **pro-:** before; see oviduct and spermiduct; also intestine and esophagus.

Proboscis (proboscidial; *plural* proboscides): cylindric projection with "true" mouth at apex; usually a pleurecbolic introvert or retractile into an acrecbolic sheath; see also rostrum.

Accessory proboscis: a proboscis-like structure in the middle of the anterior part of sole (see Carriker, 1943).

Proctodaeum: ectodermal invagination to form anus, and (Pulmonata) apparently even the intestine.

Propodium (propodial): anterior part of foot, especially when expanded above head.

Propodial groove: transverse groove demarcating head, usually from sole or mentum.

Prostate (prostatic): any glandular part of secondary spermiduct (rarely a separate organ with a duct): (Pulmonata) consisting of a few to very many club-shaped alveoli along spermiduct (or sulcus), which may be attached to, or free from uterus; *syn.* prostatic gland.

Accessory prostate: (neritoids) basal diverticulum of second prostate; it may consist of a glandular tube, with its basal swelling, prostatic caecum and common basal chamber.

Anterior part of prostate: (Lymnaeidae, F.C. Baker, 1911) the true prostate.

Duct of prostate: (Pulmonata) many and minute; (F.C. Baker, 1911) see (prostate) vas.

False prostate: (Lymnaeidae) swelling along preprostatic spermiduct.

First prostate: apical portion, when differentiated (Helicinidae).

Posterior part of prostate: (Lymnaeidae, F.C. Baker, 1911) the false prostate.

Prostatic caecum: see (accessory) prostate.

Second prostate: anterior portion, when differentiated (Helicinidae).

Thalamic prostate: (Neritidae) a first prostate.

Prosobranch: with ctenidium in front (of heart), including azygobranch and zygobranch; or belonging to the Prosobranchia.

Protandrous or **proterandric:** with male organs maturing before female ones, as in most Pulmonata.

Protogynous or **proterogynic:** opposite of protandrous.

Protractor: band of muscle drawing organ outward or anteriad; for penial protractor, which may be anterior or posterior (apical), see F.C.Baker (1911, 1945); for radular pprotractor, see H.B. Baker (1925c).

Provagina (provaginal): (neritoids) last chamber of apical oviduct; it receives (dorsal and ventral) spermathecae and opens into pallial cavity (sometimes through hypobranchial gland); (in most Helicinidae) often not separable from thalamus; *syn.* vagina.

Provaginal apparatus or complex: all structures associated with provagina.

Provaginal canal or provaginal connecting duct: between thalamus and provagina.

Provaginal orifice or aperture: opening into hypobranchial gland or pallial cavity.

Provaginal sac: (dorsal) spermatheca, on provagina or thalamus.

Pseudobranch: secondary branchia; (Planorbidae) on right (parietal) side of mantle collar.

Pseudopallium: expansion of nuchal or cephalic skin, which surrounds shell; see also shell (lap).

Ptenoglossate (Ptenoglossa): related to the Laenioglossa, but with many centrifugal teeth in radula.

Pylorus (pyloric): see stomach.

Pugio: dart on male organs; *syn.* stylet.

Pulmonary: pertaining to lung, which is the pulmonary sac.

Pulmonate: with a lung, but every pulmonate does not belong to the euthyneurous Pulmonata.

Rachiglossate: (Rachiglossa): usually with three teeth (central and one pair of laterals) in radula.

Rachis (rachidian): central line; see radula (central); *syn.* rhachis.

Radula (radular): lingual ribbon, working back and forward over cartilages in buccal bulb, often against jaw; its thin basement membrane bears very hard teeth in transverse rows, which form in radular caecum, gradually wear out, and finally break off anteriad; *syn.* glossa (glossate). See a-, doco-, pteno-, rachi-, rhipido-, steno-, taenio- and toxi-glossate.

Radular accessory plate: radular element associated with a tooth; (neritoids) part of comb or T-lateral; (Cypraeidae) detached outer part of admedian.

Radular admedian: radular lateral tooth, specifically (Taenioglossa) when only one each side of central.

Radular basal or basement membrane: thin membrane to which teeth are attached.

Radular caecum, pouch or sac: a caecum in which radula develops; the radular teeth are formed by odontoblasts (cells) but the impervious (non-staining) hard surface is added subsequently.

Radular capituliform complex: see T-lateral.

Radular cartilage or cushion: that or those over which radular ribbon is moved.

Radular central: median tooth of each transverse row; *syn.* rachidian.

Radular centrifugal: any tooth except central one; used when laterals and marginals are not distinguished.

Radular comb-lateral: (Helicinidae) comb-shaped 4th lateral with its accessory plate.

Radular complex or apparatus: radular an all accessory structures; *syn.* odontophore.

Radular cusp or cone: any lobe or point on reflected or cutting edge of tooth; it points dorso-posteriad when functioning, but usually is figured and described when flattened by a cover-glass, and sometimes when reversed (*e.g.*, outer amnicolid marginal).

Radular ectocone (ectoconal): any cusp outside of (lateral to) a mesocone.

Radular endocone or entocone: any cusp inside of (medial to) mesocone.

Radular formula: various and conflicting, but 7-6-1-6-7 usually means seven marginals and six laterals each side of a single central.

Radular lateral: tooth or teeth either side of central, and often resembling it in shape; between central and marginals; rarely used to mean marginal; *syn.* admedian.

Radular longitudinal row: includes successive teeth, which occupy same position in the transverse rows, but which may differ in cusps and even in shape.

Radular marginal: any one of outermost groups in each transverse row; commonly more specialized than laterals, and lateral to them; *syn.* pleural and rarely lateral; see also uncinus.

Radular mesocone: cusp apparently homologous to the middle one of a tricuspid central.

Radular mesometamorphosis: (Pilsbry, 1894) "All modification of the teeth proceed from the median line of the radula outwards ..." True in a general way, but modifications do proceed from other centers (*e.g.*, that between laterals and marginals); they sometimes go in the opposite direction; the central may be the least modified

tooth; and commonly the marginals are the most specialized.

Radular muscles: retractors (raspers) and protractors (returners) of radular ribbon; protractors, tensors, constrictors and elevators of radular cartilages; see Herrick (1906), H.B. Baker (1925c) and Carriker (1943, 1947).

Radular nerve: see (odontophoral) nerve.

Radular ribbon: basement membrane with attached rows of teeth.

Radular rotella: see radular cartilages.

Radular sac or sheath: usually a large radular caecum, into which radula may be partly retracted.

Radular T-lateral: (neritoids) 4th or 5th lateral and accessory plate, which with their cutting edge (reflection) are shaped like half of a mushroom or parasol; *syn.* capituliform complex.

Radular tooth or denticle: any discrete element: central or centrifugal (lateral or marginal); its anterior (reflected) edge is usually above in figures.

Radular transverse rows: usually numerous, seldom exactly transverse, almost bilaterally symmetric, and often folded into a trough posteriad, with centrals along bottom groove or angle.

Radular uncinus: an elongate marginal; specifically the ligulate ones of Rhipidoglossa.

Ramus (ramal or ramous): a branch.

Receptaculum seminis or **receptaculum seminalis:** spermatheca.

Rectum (rectal): part of hindgut along columellar side of pallial (mantle) cavity, but primitively (zygobranchs) may pass through pericardium; see adrectal and anal glands and anal nerve.

Renal and **renal organ**: see kidney.

Renopericardial pore or **renopericardial canal**: opening (10 in *Elysia)* between pericardial cavity and kidney; usually only left one retained (see oviducocoelomic).

Retensor muscle: (Arionidae) unpaired muscle, from origins of buccal and tentacular retractors; insertion on top of head or on right side of foot (equals right pedal retractor?).

Retractor: muscle that draws organ inwards or posteriad (towards apex of spire); those listed are from free retractor system of land snails, and most common of various origins are given; usually unpaired unless otherwise stated.

Atrial retractor: from right pedal or rhinophoral retractor.

Buccal retractor: from columellar or tentacular retractor, through nerve rings to buccal bulb; *syn.* pharyngeal retractor; see (buccal retractor) nerve.

Caudal retractor: continuation of columellar retractor to form tail fan; *syn.* tail retractor.

Columellar retractor: the principal (left) retractor from shell columella; branches into free retractor system; for right columellar retractor, see (mantle) retractor.

Epiphallic retractor: rarely distinct from (penial) retractor.

Eye retractor: see (ommatophoral) retractor.

Free retractor system: includes every retractor branching from columellar retractor, but a branch retractor may acquire separate origin, especially when shell is reduced.

Hyperphallic retractor: see (vergic) retractor.

Labial retractor: right and left, from rhinophoral retractor.

Lateral or lateral pedal retractor: see (pedal) retractor.

Mantle retractor: reduced right columellar retractor, from shell columella along hindgut (rectum) to around parietal angle of mantle collar, and beyond to right side of foot; *syn.* pallial retractor.

Ommatophoral retractor: right and left, from tentacular retractor; right ommatophoral retractor usually passes through penioviducal (atrial) angle; *syn.* eye retractor.

Pedal retractor: right and left, from columellar retractor, but may be fused to tail fan or to tentacular retractor; to sides of foot and, on right side, often to atrium and other terminal genitalia; *syn.* retractor pedis and lateral pedis retractor.

Penial retractor: usually from diaphragm, sometimes (primitively?) from left pedal retractor; or (secondarily!) from right pedal or either tentacular retractor; may insert on penis, penis sheath, epiphallus and/or vas; often forked when penis is branched.

Pharyngeal retractor: see (buccal) retractor.

Radular retractor: see retractor (muscles).

Rhinophoral retractor: see lower or inferior tentacular retractor.

Rostral or probiscidial retractor: retractor of mouth.

Spermathecal retractor: see spermatheca.

Tentacular retractor: right and left, from columellar or pedal retractor; (Stylommatophora) branches into ommatophoral retractor; see lower tentacular retractor: see (tentacular retractor) nerve.

Vergic retractor or retractor of vergic sac: insertion on vergic sac of penis; see penial retractor; *syn.* hyperphallic retractor.

Rhinophore (rhinophoral): special tentacle for reception of chemical stimuli.

Rhipidoglossate (Rhipidoglossa) with many ligulate (strap-shaped) radular uncini, which usually are markedly different from laterals.

Rhychodaeum: cavity around an invaginated proboscis or inside an introverted one.

Rhynchostome: opening of rhynchodaeum; called "false" mouth because "true" mouth is supposed to be at end of proboscis.

Right organ: one actually on right side of dextral animal, but on left side of a sinistral one; subintestinal ganglion and its connective with left pleural ganglion; a pallial (mantle) organ towards columellar side from heart or rectum (supposedly the originally left ones).

Rostrum: prolongation of head around mouth into a short proboscis.

Rotella: see radula (cartilages).

Salivary gland: a primarily mucous gland, left and right, opening into buccal bulb, often fused above oesophagus and rarely below; *syn.* buccal gland and organ of Semper.

Accessory or ventral salivary gland: (Stenoglossa) see Carriker (1943).

Salivary gland duct or salivary duct: from salivary gland to buccal bulb; usually opening each side of oesophagus.

Sarcobelum: see stimulator; (F.C. Baker, 1928) see verge (papilla).

Semen (seminal): see sperm.

Seminal groove or sulcus: in many land snails, a deep groove, which represents prostatic spermiduct, and runs along prostatic side of spermoviduct; also groove which represents lateral vas, that runs between female aperture and penial complex.

Seminal receptacle or sac: see spermatheca.

Seminal vesicle: (Pulmonata) enlargement, often temporary but sometimes differentiated, of ovisperm duct; (Hubendick, 1945?) see talon.

Sense (sensory) organ: any organ which is specialized as a receptor of light (see eye), touch (see tentacle and palp), balance and (perhaps) vibration (see otocyst), or chemical stimuli (see osphradium, rhinophore, epipodial tentacles and rhinophore).

Sensory endings: as in most animals, distributed throughout body, inside as well as out.

Shell: a test or exoskeleton, which is formed by the mantle collar in successive zones of growth, although the inner "nacreous" layer is added (or subtracted) by the entire surface of the mantle; it usually is attached to the animal only at the insertion of

the columellar retractor-muscle. The shell and operculum also act as organs for the storage of calcium (lime) salts, which may be added to, or dissolved from them at any time, depending largely on the concentration of bicarbonate ions, which help to determine the pH (acidity) of the blood and to buffer the blood during aestivation (dormancy during drought).

Shell lap: edge of mantle collar, reflected over or against shell, and broken only by parietal angle and by basal shell lobe; see also pseudopallium.

Left or palatal shell lap: part in left pallial or palatal region.

Right or parietal shell lap: part in right pallial or parietal region.

Shell lobe: definitely limited lobe or expansion of shell lap; *syn.* superior pallial lobe.

Basal shell lobe: over base of shell; *syn.* umbilical shell lobe.

Left or palatal shell lobe: usually well over on left side of animal.

Right or parietal shell lobe: usually behind parietal angle on right side.

Umbilical shell lobe: about same as basal shell lobe.

Sigmurethrous: with kidney and ureter S-shaped, *i.e.*, with ureter or ureteric sulcus running from anterior end of kidney to near base of kidney and then anteriad along rectum.

Sinistral: reversed animals which have all organs on opposite sides from normal dextral ones; see left and right (organs) and hyperstrophy.

Siphon (siphonal): tube, usually open along ventral side, developed from mantle collar; used primarily for respiration; *syn.* mantle siphon or pallial siphon.

Anterior siphon: basopalatal siphon, on left side of animal.

Posterior siphonal sulcus: siphonal sulcus at parietal angle, usually towards right side of animal.

S-loops: see intestine.

Sole (plantar): ventral surface of foot; see (accessory) proboscis. Bipartite or ditaxic sole: one divided into two parts by deep midventral groove; with locomotor waves alternating on halves, so animal appears to walk.

Monozonal or monotaxis sole: (Urocoptinae) sole with one (or few) but deep locomotor waves that involve entire width of sole.

Sole pore: pit rich in mucous gland-cells.

Anterior sole pore: in middle of anterior part of sole (Pomatiasidae, etc.); see also (accessory) proboscis.

Posterior sole pore: near posterior end of sole (opisthobranchs).

Sole pouch: (Stenoglossa) a posterior cavity that helps form egg capsules in female; *syn.* pedal pouch, or posterior ventral pedal gland.

Sole sulci: longitudinal grooves of bipartite or tripartite sole.

Tripartite sole: (Aulacopoda) with three longitudinal zones plainly demarcated by sole sulci; more specialized than trizonal sole.

Trizonal sole: (most land snails) without marked longitudinal sole sulci, although usually with a median zone along which locomotor waves travel, and lateral ones that slide over substratum; *syn.* undivided sole.

Sole waves or locomotor waves: visible waves of muscular contraction, which lift a transverse zone of sole, carry it forward, press it down again, and push the animal forward.

Direct sole waves: those which travel from tail towards head. Reversed or indirect sole waves: traveling from head towards tail.

Sperm or **sperma** (spermatic or spermic): fluid containing sperm cells; *syn.* semen.

Sperm duct, spermaduct or **spermatoduct:** see spermiduct.

Spermary (spermarian): see testis.

Spermatheca (spermathecal) or spermatotheca: female organ supposedly for storage of sperm or reception of spermatophore; (Pulmonata) usually at apex of vagina;

syn. bursa of bursa copulatrix, copulatory pouch (poche copulatrice) of Guiart (1900), genital or generative bladder, receptaculum seminis, seminal or sperm receptacle or sac, and Swammerdam's vesicle.

Accessory spermatheca: (Helicinidae) sac emptying into V-organ.

Dorsal spermatheca: (Helicinidae) dorsal sac on provagina or thalamus; *syn.* provaginal or vaginal sac.

Long spermatheca: (Pulmonata) with spermatheca sac in visceral mass above cephalic aorta.

Short spermatheca: (Pulmonata) with spermatheca in body cavity below cephalic artery.

Spermatheca branch to penial sheath: in Gastrodontinae.

Spermatheca diverticulum or caecum: (Pilsbry, 1894) branch of spermatheca stalk, sometimes also enlarged apically.

Spermatheca duct: spermatheca stalk; (Sagdidae) its narrower part above spermatheca retractor or caecum.

Spermatheca ligament or spermatheca retractor: seldom muscular; origin often from prostate or uterus.

Spermatheca sac: terminal enlargement; spermatheca, *sensu stricto.*

Spermatheca stalk: narrower than spermatheca sac; usually opens into apex of vagina.

Spermatheca opening: opening of s. stalk or duct; see also vaginal opening.

Ventral spermatheca or caecum: (neritoids) ventral sac on provagina or thalamus; *syn.* vaginal sac.

Spermatophore (spermatophoral): (Pilsbry, 1894) capsule containing sperm, often found in spermatheca; strictly, one with horny wall, often with "head" formed in epiphallus proper, and "tail" developed in its flagellum; *syn.* capreclus.

Spermatophore gland: (F.C. Baker, 1931) see penis.

Spermatophore sac: a sac-like spermatophore; or organ forming spermatophore (*e.g.*, epiphallus).

Spermatozoon (spermatozoan) or **sperm cell**; male cell, usually motile, which partly (mainly its nucleus) unites with ovum during fertilization.

Spermiduct (spermiducal): any tube primarily for passage of sperm; male gonaduct; (Pulmonata) often including (1) preprostatic portion which may be swollen to form a (1a) false prostate, (2) prostatic portion or prostate, (3) the (postprostatic or free) vas (deferens), and (4) the penial complex; *syn.* seminal duct, spermaduct, spermatic or spermic duct, and vas deferens.

Apical spermiduct or primary azygospermiduct: male apical gonaduct, which may include an epididymis and a testicular duct; *(Hendersonia)* also a provaginal sac.

Primary spermiduct: male primary gonoduct.

Secondary spermiduct: male secondary gonaduct, which (neritoids) may include (1) the prostate and (2) terminal chamber (Helicinidae) or duct to apex of verge, if present.

Spermovarium: see ovotestis.

Spermoviduct: common tube for both sperm and eggs; (Pulmonata) that below ovisperm duct, thus including (1) carrefour with talon, (2) spermoviduct proper, *i.e.*, any undivided uterus and seminal sulcus, with its prostatic alveoli, and even (3, Siphonariidae) a slenderer, postbulbar duct to vagina or atrium.

Spermoviduct bulb or spermoviduct uterus: (Siphonariidae) spermoviduct proper, or swollen portion, as contrasted by slenderer postuterine duct; *syn.* (Hubendick, 1945) Drüsenmasse des Spermoviducts, in part, since the more apical one is apparently the albumen gland.

Sperm sac: see spermatheca.
Sperm vesicle: see semen (vesicle).
Spiculum amoris: dart.
Stenoglossate: (Stenoglossa) usually includes toxiglossate and rachiglossate.
Stimulator: papilla or other soft structure apparently more or less analogous to dart, in atrium, penis or vagina, or on verge; *syn.* stimulator papilla, sarcobelum or dart papilla.
Stomach (stomachal or gastric): muscular enlargement of digestive canal in apical viscera, usually between oesophagus and intestine; *syn.* gizzard.
Masticatory plates or "teeth" of stomach: chitinous or calcified thickenings.
Pylorus (pyloric) of stomach: part of stomach into which liver ducts open; often separable from stomach.
Pyloric caecum of stomach: a blind pouch, sometimes spirally coiled; *syn.* pancreas, and stylotheca (F.C. Baker, 1945?).
Spiral caecum of stomach: independent of style sac in some gastropods; see (pyloric caecum of) stomach.
Stomach lobes: muscular lobes of stomach, joined by dorsal and ventral stomach tendons.
Style sac of stomach: gastric caecum containing crystalline style, but often used for any gastric or pyloric pouch; *syn.* stylotheca.
Stomatic: pertaining to mouth; *syn.* stomal.
Stomatogastric: see (buccal) ganglion.
Stomodaeum: ectodermal invagination which forms buccal bulb and oesophagus, and (Pulmonata) apparently much of stomach.
Streptoneury (streptoneurous): (Streptoneura) condition of visceral nerve-ring when twisted into a figure 8, so that left (visceral) ganglion is supra-intestinal and right one is sub-intestinal.
Style (stylic) or **stylet:** variously used for any hard rod or armature.
Crystalline style: rod developed in stomach, usually in a special caecum or sac; *syn.* hyaline style.
Penial style: see (penial) dart and verge (style).
Style sac: see (style sac of) stomach.
Vergic style: see verge.
Stylophore: see dart (sac).
Stylotheca: see (style sac and pyloric caecum of) stomach.
Sub-: under; see (subcerebral) commissure and nerve, (subesophageal) ganglion, and (subintestinal) connective, ganglion and nerve.
Sulcus: groove or furrow (extending in any direction).
Supra-: above; see (superintestinal and superesophageal) ganglion.
Suprapedal gland: a tube, often long and tortuous, below body cavity and above sole; it is lined with mucous cells and opens below mouth; *syn.* pedal gland.
Swammerdam's vesicle: see spermatheca.

Taenioglossate: (Taenioglossa) with seven teeth (central, one pair of admedians or laterals, and two pairs of marginals) in radular transverse row.
Tail (caudal): part of foot behind visceral stalk; *syn.* metapodium.
Talon: (Pulmonata) simple or branched caecum or appendix on carrefour above entrance of hermaphroditic duct; free or imbedded in albumen gland; *syn.* seminal vesicle (Hubendick, 1945?).
Tentacle (tentacular): almost any subcylindric process supposed to be tactile in function; see epipodium, nerve, pallial, pedal and retractor; *syn.* vibraculum.
Cephalic tentacle: may be one or more pairs on head; (Stylommatophora) see lower

or inferior tentacle, one of the smaller pair; for upper or superior tentacle, see ommatophore; see ommatophore (superior cephalic tentacle) and rhinophore (inferior cephalic tentacle).

Tentaculoretractor: see (tentaculoretractor) nerve.

Testis (testicular; *plural* testes): organ producing spermatozoa (sperm cells) but not ova; *syn.* spermary, see ovotestis.

Testicular duct: slender convolute duct from testis to provaginal sac or secondary gonaduct; *syn.* deferent canal of testis, epididymis (in part), and spermarian duct.

Tetraspathostyle: dart with four blades.

Thalamus (Thalamic): (Neritidae) sac into which ovarian duct and thalamic glands open; it connects with both uterus and provagina; (Helicinidae) receives V-organ and usually includes provagina, with openings of dorsal and ventral spermathecae.

Thalamic glands: (Neritidae) so-called "vitelline" ones on thalamus.

T-lateral: see radula.

Tooth (dental) or denticle: see radula.

Toxiglossate: usually with two teeth (pair of laterals) in radula and commonly with poisonous oesophageal gland.

Trabecula (trabeculate): ridge, bar or incomplete partition.

Trachea (tracheal): (Tracheopulmonata) one of air tubes into which lung is branched.

Triaulos (triaulic): (opisthobranchs) hermaphroditic gonaduct which divides into spermiduct and oviduct and has two (oviducal and spermathecal) female genital apertures.

Trochosphere or **trochophore:** early embryo of many mollusks, with apical tuft and circlet of cilia; *syn.* neoembryo (Hyatt, 1888).

Typhlosole: usually a longitudinal fold in intestine and/or stomach.

Umbilicus (umbilical): columellar hole in base of shell.

Umbilical shell-lobe: see shell-lobe.

Uncinus (uncinal): elongate radular marginal, as in Rhipidoglossa.

Ureter (ureteric): excretory duct of kidney; see heterurethrous, orthurethrous and sigmurethrous.

Complete ureter: (Sigmurethra) one extending to near pneumostome.

External ureteric opening: at end of closed ureter; variable in position; *syn.* renal or renopericardial aperture.

Incomplete ureter: (Sigmurethra) one with external ureteric opening distant from pneumostome; often continued by a ureteric sulcus.

Primary ureter: ureter supposedly a coelomomoduct; a direct continuation of kidney (see orthurethrous).

Secondary ureter: at least part along rectum.

Ureteric sulcus: groove sometimes continuing incomplete ureter towards pneumostome.

Urinary chamber: (Pulmonata) small compartment, or outer wall of pneumostome, into which complete ureter opens.

Uroduct (uroducal) or **primary uroduct:** paired coelomoduct from pericardium to mantle cavity; (azygobranchs) left uroduct supposedly becomes renopericardial canal, kidney (urocoele) and primary ureter; right uroduct, joined with primary gonaduct, supposedly forms apical gonaduct (primary azygogonaduct) and loses oviducocoelomic connection with pericardium.

Uterus (uterine): any swollen or glandular part of oviduct, in pleural or pleuropedal region; (Pulmonata) specifically that between carrefour and free (or postuterine) oviduct; function variable and may bear a sac or "nidamental" gland; it may contain eggs or embryos with or without egg shells; see ootype and oviduct (bulb); (F.C. Baker, 1911) carrefour.

Spermoviducal uterus or bulb: see spermoviduct.
Uterine gland: see "nidamental" (gland).

Vagina (vaginal): female copulatory sheath; preferably used, regardless of function, for oviducal vagina, a continuation of (postuterine) oviduct external (anterior) to entrance of spermatheca; if spermatheca is absent (or elsewhere), so is vagina; (neritoids) provagina.
Accessory shell-gland of vagina: (Valvatidae).
Atrial vagina: any a. branch or vestibule into which spermatheca opens; see atrium (vagina, and also prepuce of penis).
Oviducal vagina: vagina, *sensu stricto.*
Vaginal appendicula: (Pilsbry, 1894) apical or subapical diverticulum.
Vaginal gland: commonly only a glandular zone; see also dart (gland).
Vaginal stimulator: see stimulator.
Vaginal opening: often an external genital aperture for copulation and/or oviposition.
Vaginate (adjective, verb or noun): sheathe(d); see also introvert.
Vas (vasal; plural vasa) or vas deferens: spermiduct; (gastropods) preferably limited to duct between prostate and penial complex. Atrial or penioviducal angle of vas: where vas is often held by right ommatophoral retractor.
Lateral or imbedded vas: in ditremate forms, portion of vas imbedded in body wall; primitively an open groove.
Oviducal or prostatic vas: descending part along free or post-uterine oviduct.
Penial vas: ascending part along penial complex.
Postprostatic vas: vas, *sensu stricto.*
Vas branch to female side: b. to spermatheca (see canalis junctor), vagina or atrium *(Pittieria),* apparently for self-fertilization.
Vas opening: that into epiphallus or penis.
Vas verge or vergic papilla: any verge through which vas opens to outside, or into penial or vergic complex.
Veliger: larva characteristic of mollusks (but often absent); it has a velum and develops the protoconch; *syn.* typembryo (Hyatt, 1888).
Velum (velar): ciliated membrane, usually lobate; (F.C. Baker, 1911) see (anterior) lung-wall.
Venter (ventral or ventro-): belly side; sole of a gastropod or "bellyfoot."
Ventrad: ventrally.
Ventricle (ventricular) of heart: chamber that pumps blood into aorta.
Verge (vergic): male copulatory organ; (gastropods) preferably used for any non-introversible one (Lacaze-Duthiers, 1899, for Ancylidae), through or along which vas or epiphallus (EV) discharges sperm; *syn.* oncheiopodium, glans and penis; see also penial verge inside eversible penis (Pulmonata). Many of the compounds of penis are also applicable to the verge.
Vergic aperture: external opening of verge.
Vergic appendix or vergic caecum: terminal (basal) pouch which enters verge; *syn.* penial flagellum.
Vergic appendix sheath or sheath of vergic appendix: *syn.* sheath of penial flagellum (F.C. Baker, 1928).
Vergic epiphallus: swelling at base of verge, especially if spermatophoral.
Vergic gland: any gland which enters verge, with or without a duct.
Vergic papilla of penis: see penial verge.
Vergic sac of penis: see (sac of) penial verge.
Vergic stimulator, papilla or pilaster: any projection on verge.

Vergic stylet: horny or calcareous armature of verge or of penial verge.

Vestibule: any terminal or opening chamber; for genital vestibule, see atrium.

Vibraculum: see tentacle and palp.

Viscera (visceral; plural of viscus): internal organs, especially the apical viscera; see (visceral) ganglion, ganglion (nerve-ring), commissure and connective.

Apical viscera: viscera outside of body cavity and not enclosed by mantle cavity; in large snails, usually consisting of the liver and the organs imbedded in it; *syn.* hepatic viscera, and visceral dome, cupola, hump, mass, sac and spiral.

Pedal viscera: those in foot.

Pleural viscera: those in pleural stalk; (Pulmonata) commonly continuous with pedal viscera.

Pleuropedal viscera: those associated with (pleuropedal) body-cavity or principal haemocoele.

Visceral cavity: see haemocoele or body cavity.

Visceral mass or sac: see (apical) viscera.

Visceral stalk: slender part of body between foot and mantle collar or anterior lung wall, but actually includes pleural stalk.

Vitellus (vitelline): yolk of egg cell or ovum.

Vitelline gland: ovary, which develops yolk; but often applied to female glands of dubious function; see albumen, nidamental, thalamic and uterine gland.

Viviparity (viviparous): state, character or condition of giving birth to young ("alive") snails (like *Viviparus*); includes ovoviviparity but is contrasted to oviparity. Gastropods exhibit every intergradation between these and go beyond ovoviviparity, but are not known to attain viviparity in its (ambiguously) restricted sense (*i.e.*, placental viviparity, as in mammals).

V-organ (Helicinidae): enlarged in-shaped lower end of ovarian duct; its 2nd limb connects through a pedicel with the thalamus, and bears an accessory spermatheca

Zygobranch: (Zygobranchia) with paired (right and left) ctenidia, auricles, osphradial and uroducal organs.

Zygoneury (zygoneurous): streptoneury with a direct zygo-connective between a pleural ganglion and the visceral ganglion of the same side; most frequently between right pleural and subintestinal ganglia (right zygoneury).

Zygosis: hypothesis (1) that the concentrated visceral nerve-ring of Pulmonata is due to orthoneury accompanied by right zygoneury to an accessory ganglion between subintestinal and abdominal ganglia, and by subsequent fusion of all three ganglia; and (2) that the parietal or pallial ganglia are new centers derived from the pleural ganglia.

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A CHECKLIST AND CLASSIFICATION OF THE TERRESTRIAL PULMONATE SNAILS OF THAILAND

Somsak Panha[1]

ABSTRACT – Terrestrial pulmonate snails have been recorded from Thailand (Siam) since the 19th century. Currently this fauna is represented by 136 species, placed in 59 genera and 15 families. A taxonomic list of these species is presented.

Key words: terrestrial pulmonate snails, Thailand, Pulmonata, Stylommatophora.

INTRODUCTION

Terrestrial pulmonate snails have been recorded from Siam or Thailand since the 19th century. Gould (1844), provided the first article [on the description of land shells from Burma and Siam collected by Francis Macon]. This was followed in 1860 by Martens, who included 17 species of terrestrial pulmonate snails for Siam.

Other authors describing or listing land pulmonate snail species from Thailand during this early period were Pfeiffer (1860, 1861a,b, 1862), Dohrn (1861), Crosse & Fischer (1863), Wallace (1865), Godwin-Austen (1882, 1888, 1898), Morelet (1883, 1884, 1886, 1889, 1891a,b), Tryon (1885), Cockerell (1891) and Möllendorff (1891, 1894).

During the 20th century, the number of publications dealing with land pulmonate snails found in Thailand increased, and the fauna was becoming better known. These publications included the works of Gude (1901, 1903a,b,c, 1907, 1914), Blanford (1902, 1903), Sykes (1902), Pilsbry (1905), Godwin-Austen (1909, 1916, 1919), Schepman (1912), Fulton (1915), Cooke (1915), Kennard & Woodward (1923), Woodward (1924, 1925), Benthem Jutting (1929), Cockerell (1929), Laidlaw (1931), Tomlin (1929, 1932), Haas (1934, 1952), Tweedie (1947), Zilch (1953, 1961, 1966, 1984), Hubendick (1956), Solem (1965, 1966), Bruggen (1972), Loosjes & Loosjes-Van Bemmel (1973), Mead (1979), Thompson & Lee (1988) and Panha (1996a,b). Some of these publications were faunistic surveys, and some were mainly taxonomic in nature. Some taxonomic problems still need to be resolved, and much more information is needed on the snails' ecology, ecological physiology, and responses to human modified-environments. But more details on these aspects must await further studies.

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The list below contains 15 families, 59 genera and 136 species. Some additional taxa undoubtedly will be added as Thailand is more thoroughly surveyed.

OUTLINE OF CLASSIFICATION AND LIST OF SPECIES

Subclass Pulmonata Cuvier
Order Stylommatophora Schmidt
Superfamily Pupilloidea
Family Vertiginidae
Genus *Hypselostoma* Benson
H. holimanae Thompson & Lee
Genus *Gyliotrachela* Tomlin
G. transitans (Möllendorff)

Superfamily Buliminoidea
Family Buliminidae
Genus *Buliminus* Beck
B. siamensis Redfield
Genus *Coccoderma* Möllendorff
C. ceratina (Reeve)
Family Cerastuidae
Genus *Cerastua* Strand
C. siamensis (Redfield)

Superfamily Clausilioidea
Family Clausiliidae
Genus *Formosana* Boettger
F. cambodjensis (Pfeiffer)
Genus *Clausilia* Draparnaud
C. (Pseudonenia) kelantanese Sykes

Superfamily Achatinoidea
Family Subulinidae
Genus *Curvella* Chaper
C. puta (Benson)
Genus *Glessula* Martens
G. latestriata Möllendorff
Genus *Lamellaxis* Strebel & Pfeiffer
L. gracilis (Hutton) [introduced]
Genus *Prosopeas* Mörch
P. filiforme Möllendorff
P. walkeri (Benson)

Genus *Plicaxis* Sykes
P. mirabilis Sykes
Genus *Stenogyra* Shuttleworth
S. erecta (Benson)
Family Achatinidae
Genus *Achatina* Lamarck
A. fulica (Férussac) [introduced]

Superfamily Streptaxoidea
Family Streptaxidae
Genus *Streptaxis* Gray
S. depressa Möllendorff
S. mouhoti Pfeiffer
S. pelluceus Pfeiffer
S. porrectus Pfeiffer
S. siamensis Pfeiffer
Genus *Discartemon* Pfeiffer
D. roebeleni (Möllendorff)
Genus *Haploptychius* Möllendorff
H. mirificus (Möllendorff)
Genus *Micratemon* Möllendorff
M. prestoni (Gude)
Genus Oophana Ancey
O. strangulatus (Möllendorff)
O. subbubulus (Möllendorff)
Genus *Perrottetia* Kobelt
P. siamensis depressa (Möllendorff)
P. siamensis expansilabris (Möllendorff)
P. siamensis subglobusus (Möllendorff)

Superfamily Helicarionoidea
Family Helicarionidae
Genus *Helixarion* Férussac
H. siamensis Haines
Genus *Geotrochus* Hasselt
G. perakensis Crosse
Genus *Kaliella* Blanford
K. subsculpta Möllendorff
Genus *Hemiglypta* Möllendorff
H. siamensis (Möllendorff)
Genus *Sesara* Albers
S. megalodon Blanford
S. parva Solem
Genus *Sivella* Blanford
S. castra (Benson)
S. grubaueri Möllendorff

S. kalantanensis Möllendorff

Family Ariophantidae

Genus *Cryptozona* Mörch

C. siamensis (Tomlin)

C. praestans (Gould)

C. granulosa (Möllendorff)

Genus *Euplecta* Semper

E. bijuga (Stoliczka)

E. dichromatica Morelet

E. pataniensis Morgan

Genus *Hemiplecta* Albers

H. crossei Pfeiffer

H. danae (Pfeiffer)

H. distincta (Pfeiffer)

H. hugonis Pfeiffer

H. neptunus (Pfeiffer)

H. siamensis (Pfeiffer)

H. weinkauffiana Crosse & Fischer

H. zimmayensis Godwin-Austen

Genus *Dyakia* Godwin-Austen

D. hugonis Pfeiffer

D. salangana (Martens)

D. striata (Gray)

Genus *Parmarion* Fischer

P. setchaunensis Heude

Genus *Austenia* Nevill

A. doisutepensis Solem

Genus *Cryptaustenia* Cockerell

C. gadinodromica Solem

Genus *Cryptogirasia* Godwin-Austen

C. rubra (Godwin-Austen)

Genus *Macrochlamys* Benson

M. anceps (Gould)

M. asamurai Panha

M. dugasti Morelet

M. limbata Möllendorff

M. molecula Benson

M. pumicata (Morelet)

M. resplendens (Philippi)

Genus *Megaustenia* Cockerell

M. siamensis (Haines)

Genus *Muangnua* Solem

M. limax Solem

Genus *Sarika* Godwin-Austen

S. hainesii (Pfeiffer)

S. kautaoensis Tomlin

S. obesior (Martens)
Genus *Teraia* Solem
T. crenulata (Yen)
T. thailandica Solem
Genus *Durgella* Blanford
D. libas Solem
Genus *Naninia* Sowerby
N. benoiti Crosse & Fischer
N. mouhoti Pfeiffer
N. pedina Benson
N. subcornea Pfeiffer
Genus *Minyongia* Godwin-Austen
M. kempi Godwin-Austen
Genus *Myotesta* Collinge
M. fruhstorferi Collinge
M. punctata Collinge
Genus *Sitala* Adams
S. insularis Möllendorff
S. trochulus (Möllendorff)
Genus *Ariophanta* Desmoulins
A. laevis Müller
Genus *Ibycus* Heynemann
I. perakensis Godwin-Austen
Genus *Trochomorpha* Albers
T. capitium Benson
Family Zonitidae
Genus *Bertia* Ancey
B. cambodjensis Reeve

Superfamily Vitrinoidea
Family Vitrinidae
Genus *Vitrina* Draparnaud
V. cochinchinensis Morelet

Superfamily Camaenoidea
Family Camaenidae
Genus *Camaena* Albers
C. illustris (Pfeiffer)
Genus *Amphidromus* Albers
A. areolatus (Pfeiffer)
A. atricallosus (Gould)
A. dohrni (Pfeiffer)
A. fultoni Ancey
A. glaucolarynx (Dohrn)
A. hemicyclus Rockebrune
A. inversus annamiticus (Crosse & Fischer)

A. leucoxanthus Martens
A. metabletus Möllendorff
A. moellendorffi Haas
A. tanyai Panha
A. perversus Linnaeus
A. rhombostomus Pfeiffer
A. schomburgki (Pfeiffer)
A. semitesselatus (Morelet)
A. sinensis indistinctus Pilsbry
A. xiengensis Morelet

Genus *Chloritis* Beck
C. breviseta Pfeiffer
C. (*Trichochloritis*) *deliciosa* (Pfeiffer)
C. (*T.*) *diplochone* Möllendorff
C. (*T.*) *fouresi* Morelet
C. (*T.*) *insularis* Möllendorff
C. (*Trichochloritis*) *siamensis* Möllendorff
C. platytropis Möllendorff
C. platytropis samuiana Möllendorff
C. platytropis siamensis Möllendorff
C. tenella Pfeiffer

Genus *Ganesella* Blanford
G. capitium Benson
G. coudeini (Bavay & Dautzenberg)
G. dipplogramme Möllendorff
G. hariola carinella Möllendorff
G. perakensis Crosse
G. ptychostyla Martens

Genus *Trachia* Alber
T. gabata Gould

Superfamily Helicoidea
Family Bradybaenidae

Genus *Bradybaena* Beck
B. (*Acusta*) *brevispira* Morelet
B. fouresi Morelet
B. norodomiana Morelet

Genus *Aegista* Albers
A. (*Plectotropis*) *emensa* (Godwin-Austen)
A. (*P.*) *goniochila* Pfeiffer
A. (*P.*) *oldhami* Pfeiffer
A. (*P.*) *orthocheilis* Heude
A. (*P.*) *trichotropis* Pfeiffer
A. (*P.*) *winteriana* Pfeiffer

Genus *Cathaica* Möllendorff
C. brevispira Haines

Superfamily Succinoidea
Family Succineidae
Genus *Succinea* Draparnaud
S. cochinchinensis Pfeiffer
S. tenella Morelet

Superfamily Plectopylidoidea
Family Plectopylidae (Corillidae)
Genus *Plectopylis* Benson
P. (Chersaecia) degerbolae Solem
P. (C.) simplex Solem

ACKNOWLEDGEMENTS

This research was supported by a grant from The Thailand Research Fund (TRF), 1995. I would like to thank Dr. Robert Moolenbeek for his kind help on my visit to The Zoological Museum, Universitiet Van Amsterdam and for supplying almost all literatures, and to Chulalongkorn University for a grant to visit the Museum. Thanks also to Dr. John B. Burch for reading the manuscript.

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TWO NEW SPECIES OF *DIPLOMMATINA* FROM THAILAND (PROSOBRANCHIA: DIPLOMMATINIDAE)

Somsak Panha[1]

ABSTRACT – *Diplommatina prakayangensis* n. sp., from Prakayang Cave, Ranong Province, Thailand, is described. Except for the protoconch, radial ribs with transverse striation are present on the entire shell. On the penultimate and last whorls, the radial ribs are tubular projections, somewhat bent upward, and widened towards their tips. *Diplommatina prakayangensis* is compared to the Kalimantan species *D. miraculumdei.*

Diplommatina umpangensis n. sp., from limestone mountains near Umpang Wildlife Sanctuary, Umpang District, Tak Province, Thailand, is described. The penultimate whorl is the widest. Radial ribs on the early whorls are slightly sinuous, gradually becoming more distinct from the next whorls on. *Diplommatina umpangensis* is compared to the Samui species, *D. samuiana.*

Keywords: *Diplommatina prakayangensis, Diplommatina umpangensis,* Proso-branchia, Diplommatinidae, Thailand.

INTRODUCTION

The genus *Diplommatina* Benson 1849, which is widespread throughout Southeast Asia, includes hundreds of species (Vermeulen, 1993). Fifty species were recorded from Borneo alone by Vermeulen. Three species were reported from nearby Perak (Möllendorff, 1891), a species was described from the Samui Islands, Gulf of Siam (Möllendorff 1894), two species were found recently in southern Thailand (Panha, in press), and Panha & Burch (1996) reported five additional species of *Diplommatina* in northern and southern Thailand. The two species described in the present paper are the nineth and tenth species of *Diplommatina* known for Thailand.

***Diplommatina prakayangensis* n. sp.** (Figs. 1, 2, 3a)

Holotype: shell conical, sinistral, with 6 1/2 whorls, whorls convex. Suture deeply impressed. Constriction level with the parietal side of the peristome; collumellaris only a small bump. Tuba 3/4 whorl. After the protoconch, radial ribs with transverse striation are present on the entire shell. On the penultimate and last whorls, the radial ribs extend out into tubular projections, somewhat bent upward, and may be widened towards their

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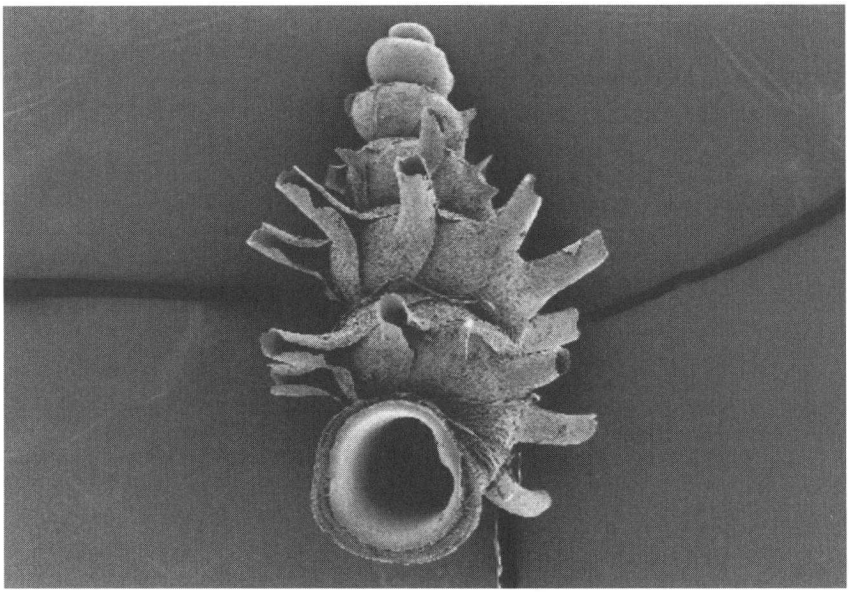

FIG. 1. *Diplommatina prakayangensis* n. sp. Holotype (CUIZM, Di 006), x17.

tips. Transverse striation occurs over the entire shell, except for the protoconch. The umbilicus is closed. The peristome is double, expanded, its palatal side not sinuous, without an edge. Length 1.7 mm; width 0.8 mm; length of aperture 0.4 mm; width of aperture 0.5 mm. The dimensions of the holotype and paratypes are shown in Table 1.

Type locality. Prakayang Cave, Ranong Province, Thailand, at 10°19'37" N, 98°48'02" E, 117 meters elevation (CUIZM, Di 006). Fig. 3a.

Etymology. The specific epithet *prakayangensis* is from the name of Prakayang Cave, Ranong Province.

Type material. The holotype (CUIZM, Di 006) is deposited in the Chulalongkorn University Zoological Museum together with five shells paratypes (CUIZM, Di 007). Other shell paratypes (six shells) (CUIZM, Di 008) are stored in the Field Museum of Natural History (FMNH), Chicago (three shells), and the University of Michigan Museum of Zoology (UMMZ), Ann Arbor (three shells). Collected by S. Panha.

Habitat and geographical distribution. *Diplommatina prakayangensis* was found on the ground and in rock crevices on a limestone mountain. The following species were also found with *D. prakayangensis: Cryptozona siamensis* (Pfeiffer 1856) and *Discartemon roebeleni* (Möllendorff 1894).

Diagnosis. *Diplommatina prakayangensis* is similar in shell morphology

FIG. 2 [facing page]. **a**, Peristome and constriction, ca. x 70; **b**, radial ribs with transverse striation, ca. x 106; **c**, inner peristome sculpture, ca. x 124.

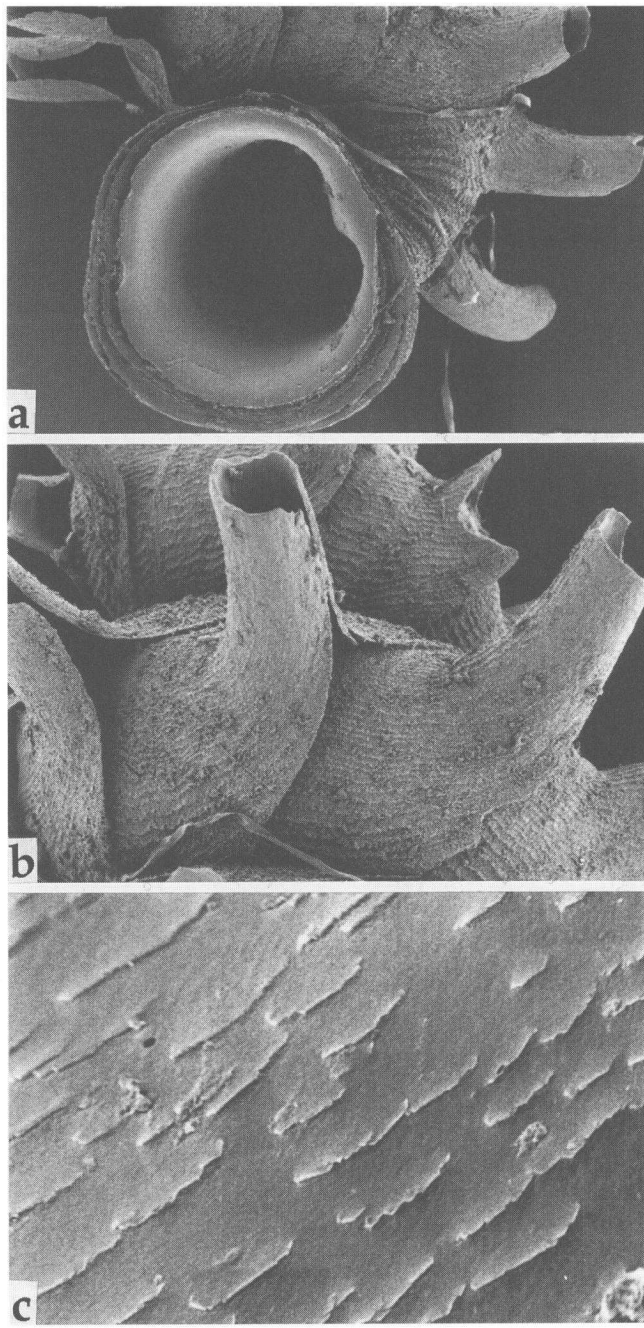
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TABLE 1. Holotype and paratype dimensions (in mm) of shells of *Diplommatina prakayangensis* n. sp.

	Shell		Aperture	
Specimens	Height	Width	Height	Width
Holotype	1.7	0.8	0.4	0.5
Paratypes				
1	2.1	1.1	0.5	0.6
2	2.1	1.1	0.5	0.6
3	2.1	1.1	0.5	0.6
4	1.9	1.0	0.5	0.6
5	1.9	1.0	0.5	0.6
6	1.9	1.0	0.5	0.6
7	1.9	1.0	0.5	0.6
8	1.8	1.0	0.5	0.5
9	1.7	0.9	0.5	0.5
10	1.7	0.8	0.5	0.5
11	1.6	0.8	0.4	0.5

to *D. miraculumdei* (Vermeulen 1993). In comparison, *D. prakayangensis* has a sinistral shell with transverse striation, while *D. miraculumdei* has spiral striation. The new species has 6 – 6 3/4 whorls, while *D.*

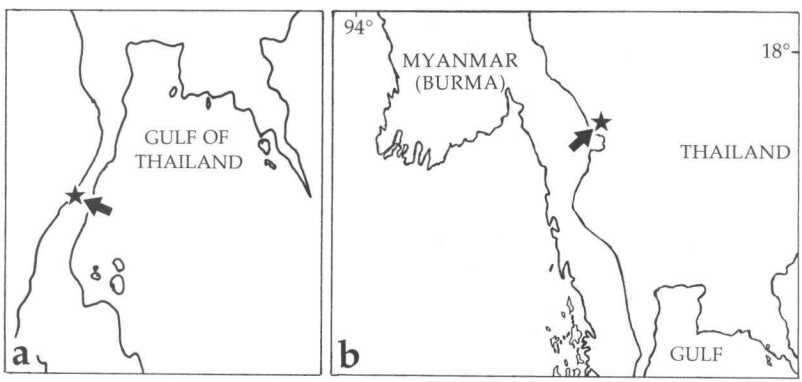
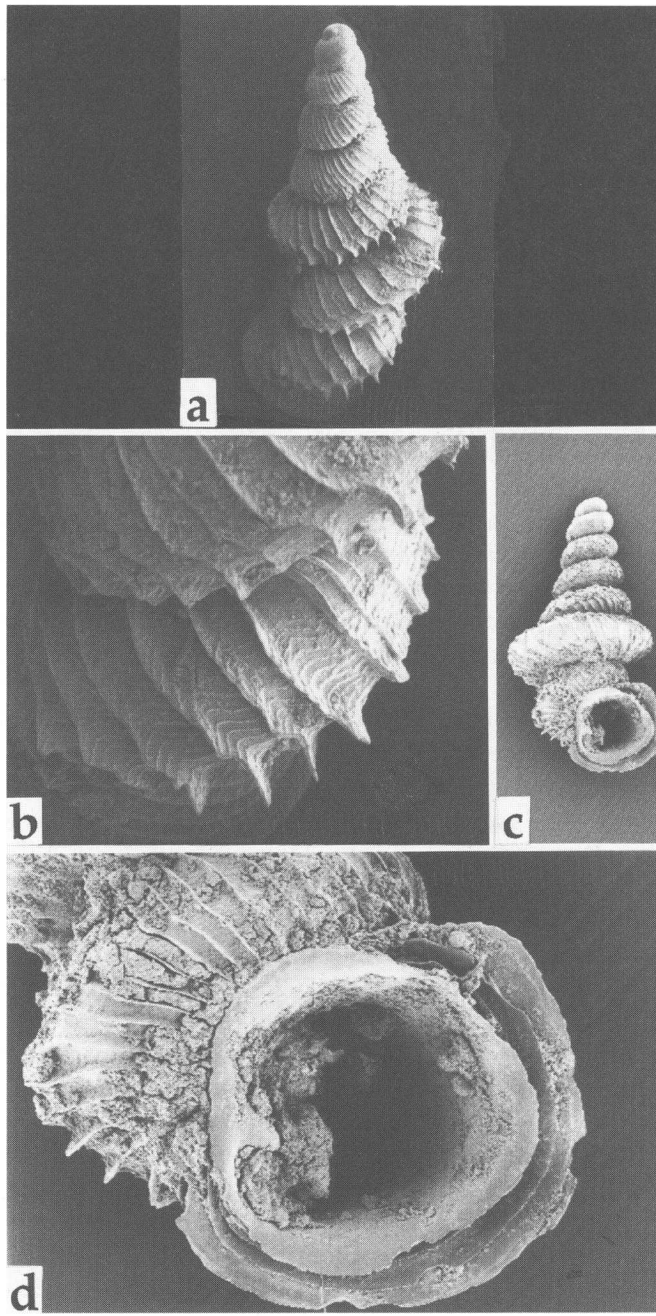


FIG. 3. Maps of Thailand showing **a**, the locality of Prakayang Cave (arrow), Ranong Province; and **b**, the area of the limestone mountain near Umpang Wildlife Sanctuary, Tak Province (arrow).

FIG. 4 [facing page]. *Diplommatina umpangensis* n. sp. **a**, Holotype (CUIZM, Di 016), adapertural side, ca. x 26; **b**, Paratype (CUIZM, Di 017) showing radial ribs and transverse striation, ca. x 79; **c**, Paratype (CUIZM, Di 017) from soil samples, ca. x 12; **d**, Paratype (CUIZM, Di 017) showing peristome, ca. x 59.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miraculumdei has 7 – 9 1/8. The inner peristome of the new species has no collumellaris.

Remarks. *Diplommatina prakayangensis* is compared to the similar Kalimantan (Borneo) species, *D. miraculumdei* Vermeulen 1993, differing from that species in its sinistral shell having 6 – 6 3/4 whorls. Some other *Diplommatina* with tubular surface projections on the shell are *D. spinosa* Godwin-Austen 1889, *D. pagodula* Bavay & Dautzenberg 1909, *D. serempakensis* Vermeulen 1993, and *D. tiara* Vermeulen 1993.

Diplommatina umpangensis n. sp.
(Figs. 3b, 4)

Description of holotype. Shell conical, dextral, with 6 3/4 whorls, convex. Suture deeply impressed. Constriction level with the parietal side of the peristome. The penultimate whorl is the widest. Tuba short. Radial ribs on the early whorls slightly sinuous, gradually becoming more distinct on the next whorls, and progressively expanding outward from the shell. Spiral striation present. Umbilicus closed; collumellaris distinct. Peristome double, expanding; palatal side without edge; basal side with edge. Height 2.0 mm; width 0.9 mm; aperture height 0.6 mm.

Type locality. Thailand, near Umpang Wildlife Sanctuary, Umpang District, Tak Province at 16°13'49" N, 098°55'12" E, 240 meters elevation (CUIZM, Di 016).

Etymology. The specific epithet *umpangensis* is used after the name of Umpang District.

Type material. The holotype (CUIZM, Di 016) is deposited in the Chulalongkorn University Zoological Museum together with 17 shells paratypes (CUIZM, Di 017). Other shell paratypes (CUIZM, Di 018), in total 22 shells are stored in The Field Museum of Natural History (FMNH), Chicago, 11 shells; University of Michigan Museum of Zoology (UMMZ), Ann Arbor, 11 shells. Collector: S. Panha. *Diplommatina umpangensis* was found in soil samples from a limestone mountiain. [*Cryptozona siamensis* (Pfeiffer 1856) was also found in this habitat.]

Diagnosis. *Diplommatina umpangensis* n. sp. is similar in shell morphology to *D. samuiana* Möllendorf 1894. In comparison, *D. umpangensis* n. sp. has higher whorls, with radial ribs expanding outward from the shell surface. The penultimate whorl is the widest. Collumellaris distinct.

Remarks. *Diplommatina umpangensis* n. sp. is compared to the some-

what similar species, *D. samuiana* Möllendorff 1894, differing in details of the radial ribs, and with transverse striation over the entire shell (after the protoconch). *Diplommatina crispata* Stoliczka 1871 of Damatha, Moulmain, British India, has more angular whorls, *D. angulata* Theobald & Stoliczka 1872, from the same locality, has a proportionately larger aperture and less developed apertural lip, and *D. angulifera* Bavay & Dautzenberg 1912 of Ban-Lao, French Indochina, has a less exaggerated penultimate whorl.

ACKNOWLEDGEMENTS

This research is supported by a grant from Programme for Biodiversity Research and Training which is a consortium of Thailand Research Fund (TRF), National Center for Genetic Engineering and biotechnology and National Science and Technology Development Agency (BRT 139035).

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Walkerana, 1995-1996, 8(19): 49-62

NEW SPECIES OF DIPLOMMATINA FROM THAILAND (PROSOBRANCHIA: DIPLOMMATINIDAE)

Somsak Panha[1] and John B. Burch[2]

ABSTRACT – Five new species of Diplommatinidae (Prosobranchia: Diplommatinidae) are described from Thailand. *Diplommatina kewlom* n. sp., *D. akron* n. sp. and *D. doichiangdao* n. sp., were collected from limestone mountains at Doichiang Dao Wildlife Sanctuary, Chiangmai Province; *D. suratensis* n. sp. was collected on a limestone mountain, Klongsang Wildlife Sanctuary, Surathani; and *D. krabiensis* n. sp. is from Tam Sua, Krabi. *Diplommatina kewlom* has a pupa-shaped, dextral shell with fine radial ribs, and lacking spiral striation. *Diplommatina akron* has a nearly pupa-shaped shell, sinistral, with stronger radial ribs, and lacking spiral striation. *Diplommatina doichiangdao* has an elongated, turreted, dextral shell with strong radial ribs with higher medial processes, and fine spiral striation. *Diplommatina suratensis* has an elongated, ribbed, sinistral shell with angular whorls lacking spiral striation. The penultimate whorl of *D. suratensis* is noticeably larger than the ultimate whorl. *D. krabiensis* has a relatively short, sinistral shell with rounded whorls. The penultimate whorl of *D. krabiensis* is somewhat larger than the ultimate whorl; the radial ribs are relatively wider spaced.

Key words: *Diplommatina akron, Diplommatina doichiangdao, Diplommatina krabiensis, Diplommatina kewlom, Diplommatina suratensis,* Prosobranchia, Diplommatinidae, Thailand.

INTRODUCTION

The land snail genus *Diplommatina* Benson 1849 occurs throughout southern, southeastern and eastern Asia and includes hundreds of species (*e.g.*, see Gude, 1921, who recorded 82 species for India and neighboring areas). Undoubtedly, many species are yet to be discovered. For example, recently Vermeulen (1993) recorded 50 species for the island of Borneo, 25 species of which were previously undescribed. The genus *Diplommatina* in Thailand is still poorly known, but recent and future land snail surveys will add significantly to the knowledge of this taxon in the country (*e.g.*, this paper and Panha, 1997).

It is noticeable that rather similar shell forms occur extralimitally, often at considerable distances. At present it is not known whether these similarities are due to morphological convergence, or to evolutionary parallelism, or because the populations belong to relic sibling species with a wider previous distribution and subsequently have experienced little evolution.

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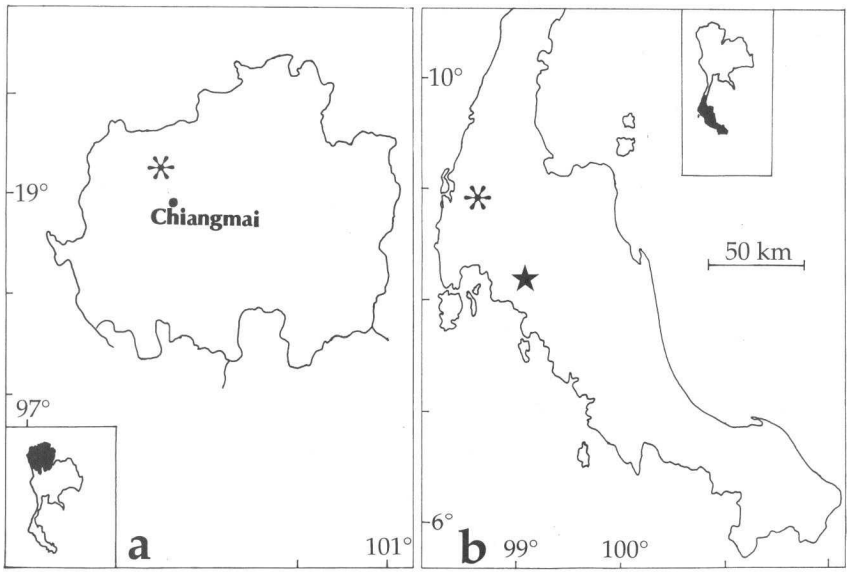


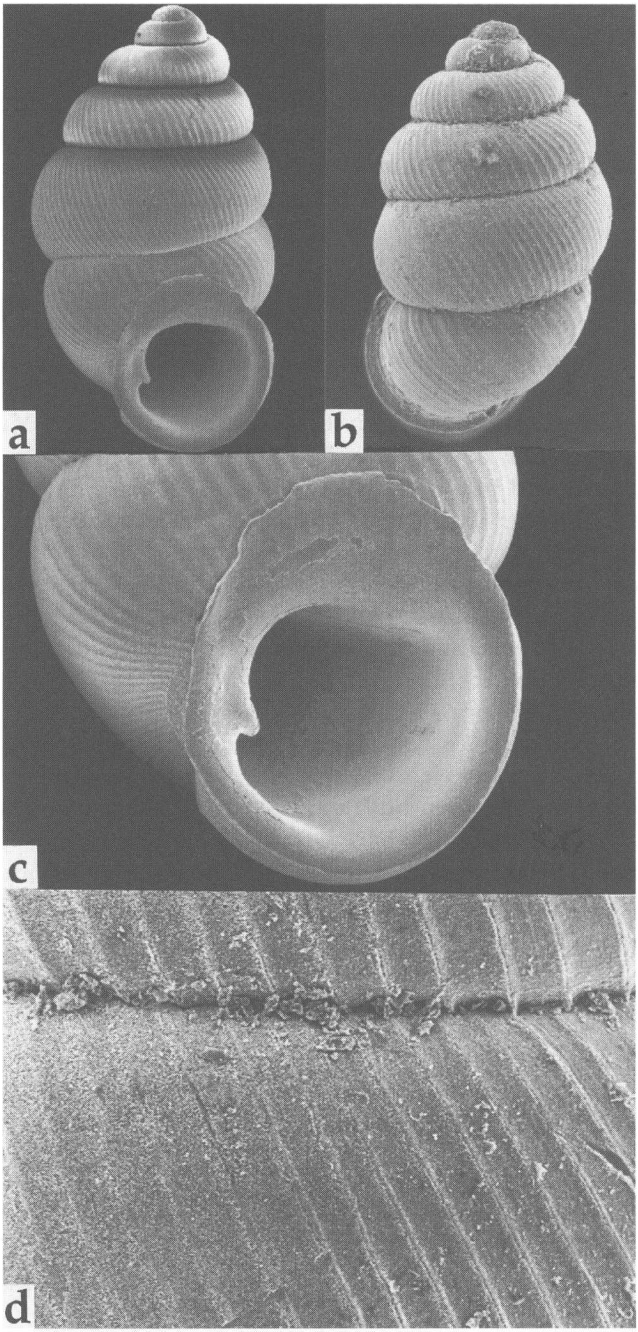
FIG. 1. Maps showing locations of type localities. **a**, Chiangmai area and Doi Chiang Dao Wildlife Sanctuary (asterisk); **b**, limestone mountain areas at Klongsang Wildlife Santuary, Surathani Province (asterisk); **c**, limestone mountain area at Tam Sua, Krabi Province (star).

During a survey of Thai land snails under the project title "Taxonomy and Ecology of Small Animals in Asian Tropics," we discovered five new species of *Diplommatina*. These new species of were collected by the authors at Doi Chiang Dao Wildlife Santuary, Chiangmai Province; at Klongsang Wildlife Santuary, Surathani Province; and at Tam Sua, Krabi Province. All of the localities are in limestone areas. These new species are described below.

Diplommatina kewlom n. sp.
(Fig. 2)

Description of holotype. Shell pupa-shaped, dextral, with 5 1/2 rounded whorls that increase regularly in size and diameter until the last whorl, which is a bit smaller in diameter than the penultimate whorl; sutures moderately impressed; tuba 1/4 whorl; sculpture of fine, low, rather closely spaced, radial ribs; spiral striae lacking; umbilicus

FIG. 2 [facing page]. *Diplommatina kewlom* n. sp. Holotype, **a**,**b**, apertural and adapertural views, X ca. 25; **c**, aperture, with expanded peristome and collumellaris, X ca. 55; **d**, radial ribs and suture, X ca. 146.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closed; aperture round, its peristome plane straight; peristome entire, double, expanded; columellaris distinct, but relatively small, directed more or less downwards and to the right when the shell is held with its apex uppermost (but directed anteriorly in relation to the normal position of the shell on the snail); shell length 2.3 mm, shell width 1.2 mm, aperture length 0.9 mm.

Type locality. Thailand, Doichiang Dao Wildlife Sanctuary, Chiang Mai Province, 19°44'16"N, 098°29'34"E, 1,700 meters elevation (CUIZM, Di 025).

Etymology. The specific epithet *kewlom* is a noun in apposition referring to the mountain summit where this species was collected.

Type materials. The holotype (CUIZM, Di 025) is deposited in the Chulalongkorn University Zoological Museum together with four shell paratypes (CUIZM, Di 026); six shell paratypes are in the Museum of Zoology, University of Michigan (UMMZ 255341), Ann Arbor; collectors: S. Panha and J.B. Burch.

Habitat and geographical distribution. *Diplommatina kewlom* is known only from the Doichiang Dao Wildlife Sanctuary, Chiang Mai Province. The snails live on limestone mountain walls and in rock crevices, with vegetation in the vicinity. The habitat for this species is almost the same as that of *D. akron* and *D. doichiangdao,* but with variation in elevation (1,300 to 1,700 meters).

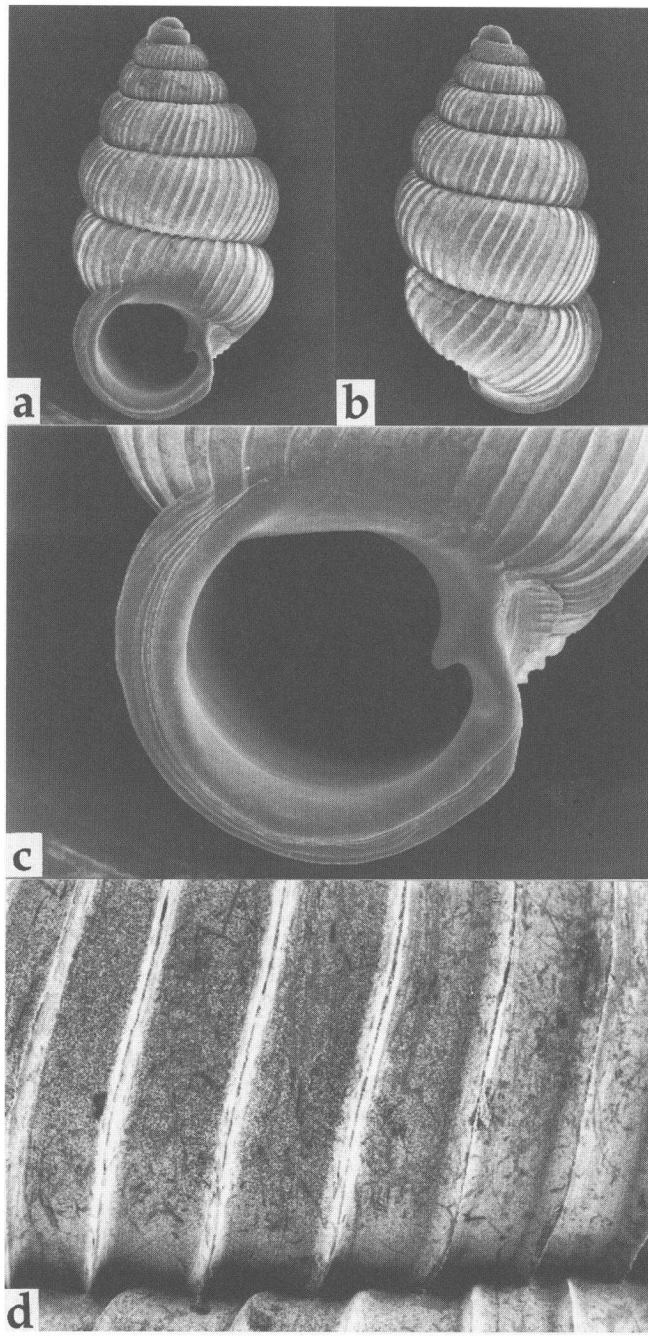
Diagnosis. Shell pupa-shaped, dextral, with about 5 1/2 rounded whorls; the penultimate whorl is a bit larger than the last whorl; sculpture of fine, low, rather closely spaced, radial ribs; spiral striae lacking; columellaris distinct, but relatively small; shell length about 2.3 mm.

Remarks. This species is very similar to *Diplommatina oviformis* Fulton 1901 from Darjeeling, India.

Diplommatina akron n. sp.
(Fig. 3)

Description of holotype. Shell rather pupa-shaped, sinistral, with 6 3/4 rounded whorls that increase regularly in size and diameter until the last whorl, which is slightly smaller in diameter that the penultimate whorl; sutures well impressed; tuba 3/4 whorl; sculpture of low, strong, moderately spaced radial ribs; spiral striae absent; umbilicus closed; aperture round, its peristome plane straight; peristome nearly entire,

FIG. 3 [facing page]. *Diplommatina akron* n. sp. Holotype, **a**,**b**, apertural and adapertural views, X ca. 11; **c**, aperture, with expanded, double-lipped peristome and collumellaris, X ca. 37; **d**, radial ribs, X ca. 111.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double, expanded; columellaris distinct, but relatively small, directed to the left and anteriorly; shell length 4.8 mm; shell width 2.4 mm; aperture length 1.6 mm. The dimensions of 10 paratypes are given in Table 1.

Type locality. Doichiang Dao Wildlife Sanctuary, Chiangmai Province, Thailand, at 19°06'18"N, 98°17'21"E, 2,160 meters elevation (CUIZM, Di 022).

TABLE 1. Holotype and paratype dimensions (in mm) of *Diplommatina akron* n. sp.

Types	Length	Width	Aperture length
Holotype	4.8	2.4	1.6
Paratype			
1	4.9	2.4	1.6
2	4.9	2.4	1.6
3	4.8	2.4	1.6
4	4.8	2.4	1.6
5	4.6	2.2	1.6
6	4.6	2.2	1.6
7	4.6	2.2	1.5
8	4.5	2.2	1.5
9	4.5	2.2	1.5
10	4.5	2.2	1.5

Etymology. The specific epithet *akron* is a Greek noun in apposition referring to top or summit; *Diplommatina akron* was collected near the summit of Doichiang Dao.

Type materials. The holotype (CUIZM, Di 022) is deposited in the Chulalongkorn University Zoological Museum together with 16 shell paratypes (CUIZM, Di 023); other shell paratypes (CUIZM, Di 026), 12 shells, have been deposited in the University of Michigan Museum of Zoology (UMMZ 255342) Ann Arbor; collectors: S. Panha and J.B. Burch.

Habitat and geographical distribution. *Diplommatina akron* is known only from the Doichiang Dao Wildlife Sanctuary. The snails live on limestone mountain walls and in rock crevices, with vegetation in the vicinity. The habitat for this species is almost the same as that of *D. kewlon* and *D. doichiangdao* n. sp., but with variation in elevation (1,900 to 2,160 meters).

Diagnosis. Shell rather pupa-shaped, sinistral, with about 6 3/4 rounded whorls; penultimate whorl slightly larger than the last whorl; sculpture of low, strong, moderately spaced radial ribs; spiral striae absent; columellaris distinct, but relatively small; shell length 4.5 - 4.9 mm.

Remarks. This species has some resemblance in shell shape to the dextral *Diplommatina germaini* Bavay & Dautzenberg 1912 from "Muong-Hum; Pac-Kha," French Indochina. *Diplommatina clausilioides* Bavay & Dautzenberg 1912 from Muong-Hum has a differently shaped aperture. *Diplommatina akron* is very similar to *D. pupaeformis* from Burma.

Diplommatina doichiangdao n. sp.
(Fig. 4)

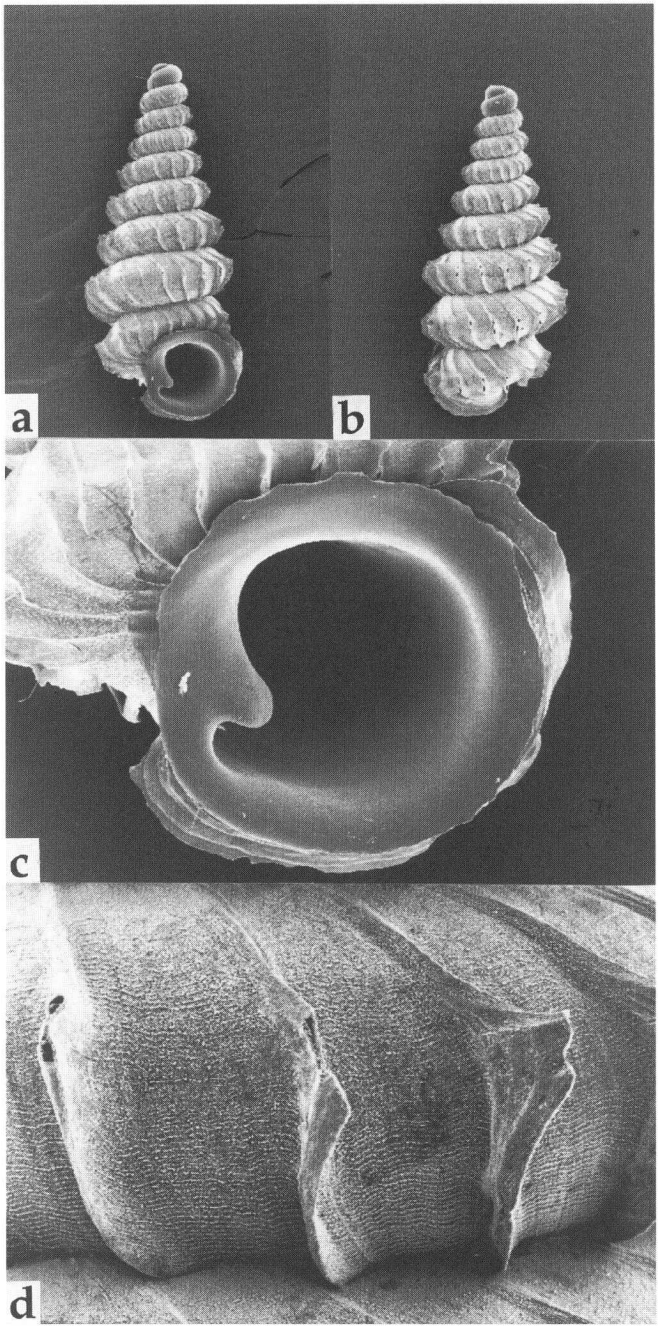
Description of holotype. Shell elongate and narrow, conical, turreted, dextral, with 9 3/4 angular whorls that increase regularly in size and diameter until the last whorl, which is smaller in diameter that the penultimate whorl; sutures deep; tuba 1/2 whorl; sculpture of thin, moderately spaced radial ribs and fine, closely spaced spiral striae; the radial ribs are somewhat sinuous, low near the sutures and come to a high point medially (*i.e.*, at or near the middle of the whorl); spiral striation is very fine; umbilicus closed; aperture round, its peristome plane straight; peristome entire, double, expanded; basal (*i.e.*, posterior) edge separated from the adjoining whorl; columellaris well developed, rather large, directed to the right and anteriorly; shell length 4.3 mm; shell width 1.8 mm; aperture length 1.1 mm. The dimensions of 10 paratype shells are given in Table 2.

Type locality. Doichiang Dao Wildlife Sanctuary, Chiangmai Province, Thailand, at 19°23'41"N, 098°55'47"E, 1,850 meters elevation (CUIZM, Di 019).

Etymology. The specific epithet *doichiangdao* is a noun in apposi-

TABLE 2. Holotype and paratype dimensions (in mm) of *Diplommatina doichiangdao* n. sp.

Types	Length	Width	Aperture length
Holotype	4.3	1.8	1.1
Paratype			
1	4.5	1.9	1.2
2	4.5	1.9	1.2
3	4.5	1.9	1.2
4	4.4	1.9	1.1
5	4.4	1.9	1.1
6	4.4	1.9	1.1
7	4.3	1.9	1.1
8	4.2	1.8	1.0
9	4.2	1.8	1.0
10	4.2	1.8	1.0


a
b
c
d

tion referring to Doichiang Dao Wildlife Sanctuary.

Type materials. The holotype (CUIZM, Di 019) is deposited in the Chulalongkorn University Zoological Museum together with 76 specimens and shell paratypes (CUIZM, Di 020); 48 other shell paratypes (CUIZM, Di 021) are stored in the Field Museum of Natural History (FMNH), Chicago, 15 specimens, and the University of Michigan Museum of Zoology (UMMZ 255343) Ann Arbor, 33 specimens; collectors: S. Panha and J.B. Burch.

Habitat and geographical distribution. *Diplommatina doichiangdao* is known so far only from the Doichiang Dao Wildlife Sanctuary in northern Thailand. The snails live on limestone mountain walls with some vegetation. They are sometimes found in rock crevices. Other snail species found in its habitat were *Chloritis* (*Trichochloritis*) *deliciosa* (Pfeiffer 1863), *C.* (*T.*) *marimberti* Bacay & Dautzenberg 1900 and *Plectopylis* (*Chersaecia*) *simplex* Solem 1966. *Diplommatina doichiangdao* was found at elevations between 1,300 and 1,850 meters.

Diagnosis. Shell elongate and narrow, conical, turreted, dextral, with about 9 3/4 angular whorls; penultimate whorl larger in diameter than the last whorl; sculpture of thin, moderately spaced radial ribs and fine, closely spaced spiral striae; the radial ribs have a high point medially; columellaris well developed, rather large; shell length 4.2 - 4.5 mm.

Remarks. *Diplommatina doichiangdao* is similar to *D. belonis* Möllendorff 1900 from Touranne, Annam [Vietnam], but that species does not have median processes on the ribs and has a more poorly developed columellaris.

Diplommatina suratensis n. sp.
(Fig. 5)

Description of holotype. Shell elongate, conical, turreted to subfusiform, sinistral, with 6 1/4 angular whorls that increase regularly in size and diameter until the last whorl, which is very distinctly smaller in diameter that the penultimate whorl; the penultimate whorl widest, imbalance location to the right when compared with peristome position; sutures deep; sculpture of thin, closely spaced radial ribs that are slightly sinuous, low near the sutures and come to a high point medially (at or near the

FIG. 4 [facing page]. *Diplommatina doichiangdao* n. sp. Holotype, **a**,**b**, apertural and adapertural views, X ca. 11; **c**, aperture, with expanded, double-lipped peristome and collumellaris, X ca. 54; **d**, radial ribs with median processes, and fine spiral striae between the ribs, X ca. 145.

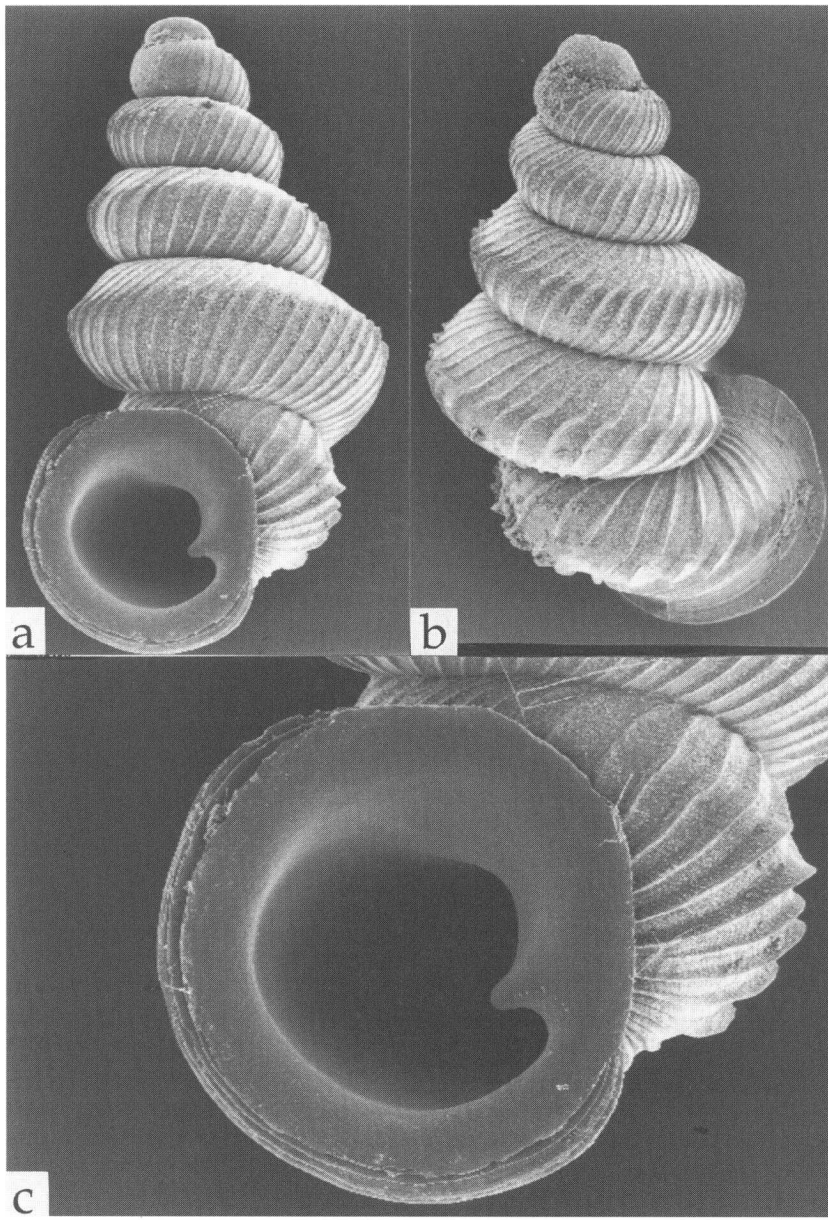


FIG. 5. *Diplommatina suratensis* n. sp. **a**, **b**, Holotype, apertural and adapertural views, X ca. 44.5; **c**, aperture showing reflected peristome and columellaris, X ca. 93.

TABLE 3. Holotype and paratype dimensions (in mm) of *Diplommatina suratensis* n. sp.

Types	Length	Width	Aperture length
Holotype	1.8	0.9	0.7
Paratype			
1	1.9	1.0	0.9
2	1.9	1.0	0.7
3	1.9	1.0	0.7
4	1.9	0.9	0.7
5	1.9	0.9	0.7
6	1.8	0.9	0.7
7	1.8	0.9	0.7
8	1.8	0.9	0.7
9	1.7	0.9	0.7
10	1.7	0.9	0.7
11	1.7	0.9	0.7
12	1.7	0.9	0.7
13	1.7	0.9	0.7

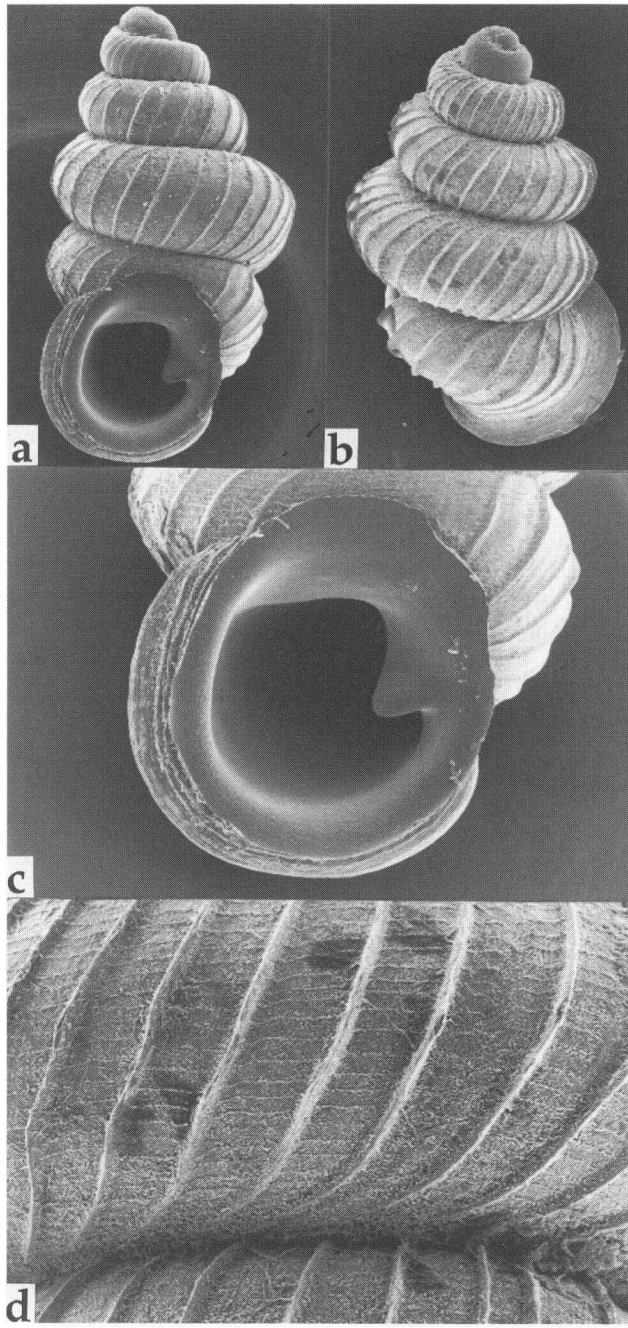
middle of the whorl); spiral sculpture absent or subobsolete (especially on the base of the shell); the radial ribs begin on the earlier whorls low and even in height, then gradually increase in prominence and become higher and pointed at the angle of the shell periphery; umbilicus closed; aperture round, its peristome plane straight; peristome entire, double, expanded, separated from the base of the body whorl; columellaris rather well developed, directed to the left and only slightly anteriorly; shell length 1.8 mm; shell width 0.9 mm; aperture length 0.7 mm. The dimensions of 13 paratype shells are given in Table 3.

Type locality. Klongsang Wildlife Santuary, Surathani Province at 8°58'3"N, 98°41'54"E, 170 meters elevation (CUIZM, Di 028), Thailand.

Etymology. The specific epithet *suratensis* is from the name of Surathani Province, where the specimens were found.

Type material. The holotype (CUIZM, Di 028) is deposited in the Chulalongkson University Zoological Museum, together with seven other paratype shells (CUIZM, Di 029); additional shell paratypes (CUIZM, Di 030), six shells in total, are stored in the University of Michigan Museum of Zoology (UMMZ 255344), Ann Arbor; collectors: S. Panha and J.B. Burch.

Habitat and geographical distribution. Klongsang Wildlife Santuary, Surathani Province. The snails were found on limestone walls with some vegetation. *Discartemon roebeleni* (Möllendorff 1894) was also found in this habitat.


a
b
c
d

Diagnosis. Shell elongate, conical, turreted to subfusiform, sinistral, with about 6 1/4 angular whorls; last whorl distinctly smaller in diameter that the penultimate whorl; sculpture of thin, closely spaced radial ribs, low near the sutures and come to a high point medially; spiral sculpture absent or subobsolete; columellaris rather well developed; shell length 1.7 - 1.9 mm.

Remarks. The large, angular penultimate whorl of *Diplommatina suratensis* is similar to that of the dextral species *D. crispata* Stoliczka 1871 from Damotha, British India, and *D. angulifera* Bavay & Dautzenberg 1912 from Ban Lao, French Indochina.

Diplommatina krabiensis n. sp.
(Fig. 6)

Description of holotype. Shell fusiform, sinistral, with 5 3/4 rounded whorls that increase regularly in size and diameter until the last whorl, which is distinctly smaller in diameter than the penultimate whorl; sutures deep; sculpture of moderately stout, rather widely spaced radial ribs and fine, moderately spaced spiral striae; the radial ribs are mostly straight, and are low on the third whorl; on later whorls, the radial ribs are higher at the shell periphery, each having there a roundly or obtusely angular low projection; umbilicus closed; aperture round, its peristome plane straight; peristome entire, double, expanded, palatal side sinuous, without edge, basal side with an edge; columellaris well developed, relatively large, directed to the left and only slightly anteriorly; shell length 1.7 mm; shell width 0.9 mm; aperture length

TABLE 4. Holotype and paratype dimensions (in mm) of *Diplommatina krabiensis* n. sp.

Types	Length	Width	Aperture length
Holotype	1.7	0.9	0.7
Paratype			
1	1.7	0.9	0.7
2	1.7	0.9	0.7
3	1.7	0.9	0.7
4	1.7	0.9	0.7
5	1.7	0.9	0.7
6	1.6	0.9	0.7

FIG. 6 [facing page]. *Diplommatina krabiensis* n. sp. Holotype, **a**, **b**, apertural and adapertural views, X ca. 34; **c**, aperture, with expanded, double-lipped peristome and collumellaris, X ca. 71; **d**, radial ribs, and fine spiral striae between the ribs, X ca. 141.

0.7 mm. The dimensions of six paratype shells are given in Table 4.

Type locality. Tam Sua, Krabi Province, at 8°7'32"N, 98°55'31"E, 140 meters elevation (CUIZM, Di 031), Thailand.

Etymology. The specific epithet *krabiensis* is from the name of Krabi Province, the place we collected the specimens.

Type material. The holotype (CUIZM, Di 031) is deposited in the Chulalongkorn University Soological Museum together with three paratype shells (CUIZM, Di 032); three shell paratypes (CUIZM, Di 033) are stored in the University of Michigan Museum of Zoology (UMMZ 255345), Ann Arbor; collectors: S. Panha and J.B. Burch.

Habitat. *Diplommatina krabiensis* Tam Sua, Krabi Province. The snails were found in soil samples from a limestone mountain. *Cryptozona siamensis* (Pfeiffer 1856) was also found where the soil samples were taken.

Diagnosis. Shell fusiform, sinistral, with about 5 3/4 rounded whorls; last whorl very noticably smaller in diameter than the penultimate whorl; sculpture of moderately stout, rather widely spaced radial ribs and fine, moderately spaced spiral striae; the radial ribs with a high point at the shell periphery; columellaris well developed, relatively large; shell length 1.6 - 1.7 mm.

ACKNOWLEDGEMENTS

This research was supported by a grant (BRT 139035) from the Program for Biodiversity Research and Training, which is a consortium of the Thailand Research Fund (TRF), the National Center for Genetic Engineering and Biotechnology, and the National Science and Technology Development Agency (BRT 139035). The research was also supported, in part, by the Ministry of Education, Sciences and Culture, Japan. To the following members of our team, we would like to thank Dr. M. Matsui, Dr. T. Hikida, D.K. Araya, Dr. H. Ota, Mr. M. Toda, Mr. P. Dumrongrojwatana, and people from Ban Chiang Dao Village. All of them helped make our field studies very productive. We also thank Dr. H. Don Cameron, Professor of Greek and Latin, University of Michigan, for reviewing the names of the new species.

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STATUS SURVEY FOR FEDERALLY LISTED ENDANGERED FRESHWATER MUSSEL SPECIES IN THE PAINT ROCK RIVER SYSTEM, NORTHEASTERN ALABAMA, U.S.A.

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ABSTRACT – The U.S. Department of Interior, Fish and Wildlife Service, Jackson Area Office contracted with the Tennessee Valley Authority to a conduct a freshwater mussel survey for federally listed endangered species known to occur in the Paint Rock River system, northeastern Alabama. Survey results will provide information necessary for future recovery and management of these species and enhance distributional information of other freshwater mussel species collected. The survey included qualitative sampling at 25 mainstem and tributary sites throughout the river system.

Forty-one mussel species were found during the present survey and three of these were relicts. Four federally listed endangered species *(Fusconaia cor, F. cuneolus, Lampsilis virescens* and *Toxolasma cylindrellus)* were reported alive or fresh-dead. Four additional federally listed species *(Lampsilis abrupta, Epioblasma walkeri, Pleurobema plenum* and *Villosa trabalis)* reported historically from the Paint Rock, were not found.

The mussel fauna and river habitat of the Paint Rock River system has not recovered from extensive stream channelization in the mid-1960s. This problem is continually aggravated by nonpoint source pollution resulting from agricultural land usage along the river. Cattle access have caused streambank erosion and destabilization of river substrate. The mussel fauna may continue to decline until appropriate measures are taken to minimize stream perturbations.

Key words: mussels, endangered species, Paint Rock River system, Alabama.

INTRODUCTION

In January 1991, the U.S. Department of Interior, Fish and Wildlife Service (USFWS), Jackson Area Office, entered into a cooperative agreement (No. 14-16-0004-90-959) with the Tennessee Valley Authority (TVA Contract No. TV-83O85V) to conduct a freshwater mussel survey in the Paint Rock River system, Alabama. The purpose of the survey was to update the current status of five federally listed endangered mussel species including: *Lampsilis abrupta, L. virescens, Toxolasma cjlindrellus, Fusconaia cor* and *F. cuneolus.* All five species were reported during the last 15 years by TVA biologists and documented in USFWS recovery plans. Three additional federally

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listed species *(Epioblasma walkeri, Pleurobema plenum* and *Villosa trabalis)* are reported in the literature as occurring in the river system. Results from the present survey will provide information necessary for future recovery and management of these species and enhance distributional information of other freshwater mussel species.

Literature Review

The Paint Rock River and three of its largest tributaries (Larkin and Estill Forks, and Hurricane Creek) have a number of federally listed or candidate mussel species reported either from the literature or individual field collection records. Eight species are federally listed, three are candidate species for federal listing, and two were former candidate species which are now considered extinct. The state of Alabama also lists 14 mussel species found in the Paint Rock River system for special protection status (Table 1) (Cox, 1990). Cox did not include two federally listed endangered species *(Epioblasma walkeri* and *Pleurobema plenum)* which have not been reported from the Paint Rock since Ortmann (1925). Three extensive mussel surveys have been conducted in the Paint Rock River system (Ortmann, 1925; Isom & Yokley, 1973; and Ahlstedt, 1991). Ortmann (1925) during his study of the naiad fauna of the Tennessee River system below Walden Gorge reported 46 freshwater mussel species, including subspecies. Ortmann's species list included museum records from shell material collected by H.H. Smith, H.E. Wheeler, B. Walker, and Simpson (1914). Six mussel species in his report are now federally listed.

During the mid-1960s, Isom & Yokley (1973) reported 30 mussel species in the Paint Rock and five in Larkin Fork. Of these, three are currently listed federally. In their survey, which also included the Flint River, they reported the mussel fauna had declined by approximately 42% over the number of species reported by Ortmann.

In 1980, TVA initiated the Cumberlandian Mollusk Conservation Program (CMCP) to update the status of Cumberlandian mussel species in selected streams in the Tennessee Valley and to identify stream reaches potentially suitable to receive mussel transplants (Jenkinson, 1981). The Paint Rock River and tributaries (Estill Fork and Hurricane Creek) were extensively surveyed in 1980 (Ahlstedt, 1991). Twenty-five mussel species were found, including four federally listed endangered species. One additional federally endangered species, *Lampsilis abrupta* (one specimen), was later found in the lower Paint Rock (PRRM 17.0) in 1983 by USFWS and TVA biologists (USFWS 1985a). This

TABLE 1. Endangered, threatened, and other sensitive status mussel species known from the Paint Rock River drainage (Cox, 1990).

Scientific Name	Common Name	Status	
		Federal	Alabama
Actinonaias pectorosa	pheasantshell	—	Endangered
Alasmidonta marginata	elktoe	—	Special concern
Epioblasma biemarginata	angled riffleshell	Former candidate	Extinct
Epioblasma lenior	narrow catspaw	Former candidate	Extinct
Epioblasma triquetra	snuffbox	—	Endangered
Fusconaia barnesiana	Tennessee pigtoe	—	Endangered
Fusconaia cuneolus	fine-rayed pigtoe	Endangered	Endangered
Fusconaia cor	shiny pigtoe	Endangered	Endangered
Lampsilis abrupta	pink mucket	Endangered	Endangered
Lampsilis ovata	pocketbook	—	Endangered
Lampsilis virescens	Alabama lamp	Endangered	Endangered
Lexingtonia dolabelloides	slabsided pearly mussel	Candidate, category 2	Endangered
Medionidus conradicus	Cumberland moccasinshell	—	Endangered
Obovaria subrotunda	round hickorynut	—	Endangered
Pleurobema oviforme	Tennessee clubshell	Candidate, category 2	Endangered
Ptychobranchus fasciolaris	kidneyshell	—	Special concern
Quadrula cylindrica cylindrica	rabbitsfoot	—	Endangered
Toxolasma cylindrellus	pale lilliput	Endangered	Endangered
Toxolasma lividus	purple lilliput	Candidate, category 2	Endangered
Trucilla truncatus	deertoe	—	Threatened
Villosa taeniata	painted creekshell	—	Endangered
Villosa trabalis	Cumberland bean	Endangered	Endangered

was the first documentation of this species in the river.

Three site-specific surveys for freshwater mussels have been reported from the Paint Rock River. In 1981, TVA biologists conducted quantitative mussel habitat mapping at one site in the upper Paint Rock (PRRM 60.0). Ten mussel species (none endangered) were observed (Barr *et al.*, 1986). Two site assessments for mussels were performed on the Paint Rock by TVA in 1984 and 1986. During the 1984 survey at Alabama highway 72 bridge crossing (PRRM 26.5), six mussel species were moved upstream from a proposed new bridge site. One fresh-dead specimen of endangered *Fusconaia cor* was found. In 1986, a mussel survey was conducted in the Paint Rock River (PRRM 56.4) in the vicinity of a road diversion project. Ten mussel species were found in-

cluding a relict specimen of endangered *Lampsilis virescens.*

Two other sources of information concerning freshwater mussels in the Paint Rock are provided by Herb Athearn and Don Manning (personal communication). Herb Athearn's field collection records from the mid-1950s through 1969 contain four species from the Paint Rock, five from Larkin Fork, and one from Estill Fork. Three federally endangered species *(Lampsilis virescens, Fusconaia cor* and *Toxolasma cylindrellus)* were included in his records. Don Manning collected 29 mussel species from the Paint Rock (no site locations) in 1990, including federally endangered *Fusconaia cor, F. cuneolus* and *Lampsilis virescens.* Four mussel species, including endangered *Toxolasma cylindrellus,* were also reported by Manning from Larkin Fork.

Project Area

The Paint Rock River is located in northeast Alabama and flows southwest 60 river miles where it enters the Tennessee River at Tennessee River Mile (TRM) 343.2 (Wheeler Reservoir). The lower 13 miles of the river is in the impounded portion of the reservoir. The drainage area for the Paint Rock encompasses 458 square miles and borders the southern edge of the Cumberland Plateau physiographic province (TVA, 1970). Two major tributaries, Estill Fork and Hurricane Creek flow south from Tennessee and join to form the headwaters of the Paint Rock. The river is surrounded by forested mountains while the river valley floodplain is flat and almost entirely in agricultural production for soybeans, cotton, corn, milo, and beef cattle.

The freshwater mussel fauna in the Paint Rock River system was probably severely impacted by extensive stream channelization and removal of snags and riverbank timber by the U.S. Army Corps of Engineers (USACOE) during the mid-1960s. Included in the channelization project were the lowermost reaches of Larkin and Estill Forks and Hurricane Creek. The mussel fauna in the river continues to be jeopardized by siltation from agricultural nonpoint sources and bank erosion from previous channelization and poor farming practices. Another threat to the mussel fauna is the spraying of herbicides and pesticides on cotton and bean fields as well as the application of fertilizers. Cotton and bean spraying is a common practice throughout agricultural farmland in the watershed. The potential damage to aquatic organisms from runoff or the accidental spillage of chemicals when filling water tank trucks during low-flow condi-

tions at river access points may be adding to the demise of the mussel fauna in the river. It is uncertain what effects agricultural chemicals have upon juvenile or adult freshwaler mussels. Mussels have never been used as test animals to determine what concentrations or levels are safe.

MATERIALS AND METHODS

Initially, the Paint Rock River was scheduled for float-survey by boat, but due to extreme low-flows, fallen trees, and drift, the river was sampled at road, ford, and foot trail access points. Topographic maps (7.5-minute) were used for navigation and sample site location.

Freshwater mussel sampling was conducted from July 15-26, 1991. Water levels were extremely low, with excellent water clarity at most sites for snorkeling. Because of time constraints and funding, sites where endangered species were previously reported were sampled first. Each site was sampled by a three-man crew consisting of a biologist and two biological technicians. Methods used for collecting mussels included snorkeling, visual searching, digging, and walking the streambanks for shells in muskrat middens.

Collecting continued in all habitats at each site (minimum three man-hours) until the crew leader was satisfied that no additional species were present. At sites reported to contain endangered species, six man-hours was spent searching for and determining the areal extent of the population. All freshwater mussels encountered were sorted by species, identified by the crew leader, and counted. Records kept on the qualitative search included site location, number of man-minutes of search time, collection techniques, and numbers of live, fresh-dead (shells with shiny nacre and meat present), and relict (dull nacre, broken shell) specimens of each mussel species found. Live specimens were returned to suitable habitat at the site. Fresh-dead and relict shells were labeled and taken to the TVA Aquatic Biology Lab in Norris, Tennessee for cataloging and storage. All live and fresh-dead endangered mussel species were photographed, measured to the nearest 0.1 millimeter using a dial calipher, and aged. Measurements taken included maximum anterior-posterior length, maximum height from anterior of umbos to ventral margin, and maximum thickness across the two valves. Age of each species was determined by counting the external growth increments (annuli) on the shell. Because of the scarcity and the amount of time spent searching for endangered freshwater mussels, no quantitative samples were taken.

RESULTS AND DISCUSSION

Mussel sampling was conducted for federally listed endangered species at 25 sites in the Paint Rock River system: 18 sites in the Paint Rock River, one in Larkin Fork, two in Estill Fork, and four in Hurricane Creek (Table 2, Fig. 1).

A total of 41 mussel species (1370 specimens) were found including: 35 species in the Paint Rock, 7 in Larkin Fork, 10 in Estill Fork, and 15 in Hurricane Creek (Table 3). Fresh-dead shells were so recent with meat still present in shell that both live and fresh-dead to-

TABLE 2. Location of all freshwater mussel collecting sites in Paint Rock River (PRRM), Larkin Fork (LFRM), Estill Fork (EFRM), and Hurricane Creek (HCM), July 1991.

Site	River Mile	Location
	PRRM	
1	13.3	Buck Ford – Madison/Marshall County, Ala.
2	16.0	Fishtrap Ford – Madison/Marshall County, Ala.
3	16.9	Near Maple Ford at Whittaker Narrows – Marshall County, Ala.
4	20.9	Butler Mill – Madison/Marshall County, Ala.
5	24.5	Hellum Ford – Madison County, Ala.
6	26.4	Downstream U. S. Route 72 bridge – Jackson County, Ala.
7	30.5	Ford in town of Paint Rock – Jackson County, Ala.
8	32.5	Upstream from Cole Spring Branch – Jackson County, Ala.
9	38.7	Walker Mill Ford – Jackson County, Ala.
10	43.1	Upstream Paint Rock River oxbow – Jackson County, Ala.
11	44.8	Upstream bridge at Little Nashville – Jackson County, Ala.
12	46.3	Ford upstream from private bridge construction – Jackson County, Ala.
13	47.9	One mile downstream from bridge at Hollytree Jackson County, Ala.
14	50.4	1.5 miles upstream from bridge at Hollytree Jackson County, Ala.
15	51.4	Above bridge – Jackson County, Ala.
16	59.0	Downstream of Ford – Jackson County, Ala.
17	59.6	Ford to Henshaw Cove – Jackson County, Ala.
18	60.0	Confluence of Estill Fork and Hurricane Creek – Jackson County, Ala.
	LFRM	
19	0.5	State Route 65 Bridge – Jackson County, Ala.
	EFRM	
20	0.1	Above Paint Rock River Confluence – Jackson County, Ala.
21	1.1	Freedom Bridge – Jackson County, Ala.
	HCM	
22	0.1	Above Paint Rock River confluence – Jackson County, Ala.
23	1.6	Ford to Anderson Cemetary – Jackson County, Ala.
24	3.0	Ford to Bishop Spring – Jackson County, Ala.
25	4.0	Private Ford – Jackson County, Ala.

tals were combined. Age and growth measurements for federally listed endangered species are presented in Table 4.

Nineteen species were represented by five or fewer specimens; however, the rarity of six of these species *(Anodonta grandis, Ellipsaria lineolata, Lampsilis teres, Ligumia recta, Quadrula metanevra* and *Quadrula nodulata)* can be attributed to stream size since all are more often associated with larger rivers. Three of the 19 species *(Lasmigona complanata, Quadrula quadrula* and *Truncilla donaciformis)* were reported as relicts (stained or broken shells), and are also components of larger streams.

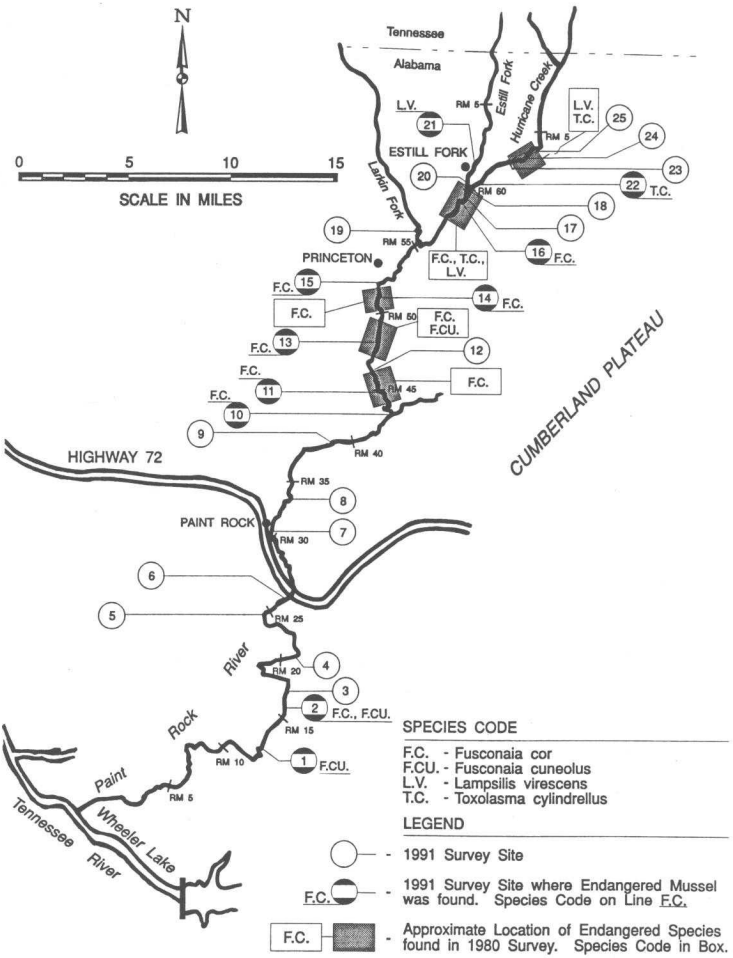

FIG 1. Paint Rock River, Larkin Fork and Hurricane Creek mussel sampling sites.

The single specimen of *Lasmigona holstonia,* a small headwaters species is a new record for the drainage with one live specimen found in Hurricane Creek (site 25).

The most abundant species found was *Lexingtonia dolabelloides* which comprised 23 percent of the total, followed by *Amblema plicata* (13%), *Villosa iris* (8%) and *Potamilus alatus* (8%). Sites 2, 4 and 10 (Table 3) contained the most diverse fauna with between 18 and 20 mussel species. Some pool habitats downstream from site 10 contained good concentrations of *Cyclonaias tuberculata, Amblema plicata* and *Potamilus alatus.* These species are more typically found in deeper pools con-

TABLE 3. Paint Rock River, Larkin Fork, Estill Fork, and Hurricane Creek qualitative mussel survey data.

		Paint Rock River													
Species	Site River Mile	1 13.3	2 16.0	3 16.9	4 20.9	5 24.5	6 26.4	7 30.5	8 32.5	9 38.7	10 43.1	11 44.8	12 46.3	13 47.9	14 50.4
Alasmidonta viridis		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Amblema plicata		5	—	1	9	6	1	2	17	14	68	—	R	1	6
Anodonta grandis		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cyclonaias tuberculata		6	10	47	7	10	—	3	7	—	7	—	R	—	2
Epioblasma triquetra		2	6	2	2	—	—	—	—	—	—	—	—	—	—
Ellipsaria lineolata		1	—	2	—	—	—	1	—	—	—	—	—	—	—
Elliptio dilatata		—	—	—	—	1	—	—	—	—	—	—	—	—	—
Elliptio crassidens		2	3	2	—	—	—	—	1	—	2	—	—	—	—
Fusconaia barnesiana *		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fusconaia cor *+		—	2	—	—	—	R	R	—	—	21	1	R	1	1
Fusconia cuneolus *+		1	1	—	—	—	—	—	—	—	—	—	—	—	—
Lampsilis fasciola		—	5	3	2	1	1	—	—	R	5	—	—	R	1
Lampsilis ovata		4	4	1	5	—	—	2	4	1	16	1	2	2	3
Lampsilis teres		2	—	—	2	—	—	—	—	—	—	—	—	—	—
Lampsilis virescens *+		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lasmigona complanata		—	—	—	—	—	—	R	—	—	—	—	—	—	—
Lasmigona costata		—	—	1	1	—	R	1	1	—	23	—	—	1	2
Lasmigona holstonia *		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptodea fragilis		—	3	—	2	—	—	1	2	—	—	—	—	—	—
Lexingtonia dolabelloides *		10	53	13	21	10	—	3	1	—	26	—	2	—	—
Ligumia recta		—	1	—	—	—	—	—	—	—	—	—	—	—	—
Medionidus conradicus *		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Megalonaias nervosa		3	7	16	8	3	1	2	5	—	2	—	—	—	—
Obliquaria reflexa		4	1	1	1	—	—	4	R	—	26	—	—	—	—
Obovaria subrotunda		—	—	—	—	—	—	R	—	—	1	—	—	R	—
Pleurobema cordatum		—	R	7	—	—	—	—	1	—	—	—	—	—	—

Pleurobema oviforme *	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Potamilus alatus	8	4	2	14	6	15	17	—	—	31	—	1	1	1
Ptychobranchus fasciolaris	—	—	—	—	1	—	—	R	1	6	—	1	—	1
Quadrula cylindrica	2	—	—	1	R	—	3	1	—	1	—	4	—	—
Quadrula metanevra	2	1	—	—	—	—	1	—	—	—	—	—	—	—
Quadrula nodulata	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Quadrula pustulosa	—	4	2	2	1	R	—	2	—	3	—	—	—	—
Quadrula quadrula	—	—	—	R	—	—	—	—	—	—	—	—	—	—
Toxolasma cylindrellus *+	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Toxolasma lividus *	18	4	33	3	1	1	2	—	—	—	—	2	—	—
Tritogonia verrucosa	—	—	—	1	—	—	—	—	—	—	—	2	2	2
Truncilla donaciformis	—	—	—	—	—	R	—	—	—	—	—	—	—	—
Truncilla truncata	—	—	—	—	—	—	—	1	—	2	—	—	—	—
Villosa iris *	—	2	1	1	R	1	—	1	—	2	—	1	3	1
Villosa vanuxemensis *	14	12	2	5	—	2	2	2	—	4	1	3	1	—
Total number of mussels	84	123	136	88	40	22	44	46	16	246	3	18	13	21
Total number of species	16	19	17	20	12	11	17	16	4	18	3	12	11	11

* Cumberlandian species (12)
\+ Endangered species (4)
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TABLE 3. (cont.)

		Paint Rock				Larkin Fork	Estill Fork			Hurricane Creek				
	Site	15	16	17	18	19	20	21	22	23	24	25		%
Species	River Mile	51.4	59.0	59.6	60.0	0.5	0.1	1.1	0.1	1.6	3.0	4.0	Totals	comp.
Alasmidonta viridis		—	—	—	—	—	—	—	—	—	2	—	2	0
Amblema plicata		1	1	R	—	R	—	14	—	2	26	8	182	13
Anodonta grandis		—	—	—	—	1	—	—	—	—	—	—	1	0
Cyclonaias tuberculata		—	—	—	—	—	—	—	—	—	—	—	99	7
Epioblasma triquetra		—	—	—	—	—	—	—	—	—	—	—	12	1
Ellipsaria lineolata		—	—	—	—	—	—	—	—	—	—	—	4	0
Elliptio dilatata		—	—	—	—	—	—	—	—	—	—	—	1	0
Elliptio crassidens		—	—	—	—	—	—	—	—	—	—	—	10	1
Fusconaia barnesiana *		—	—	1	—	—	—	—	—	—	—	—	1	0
Fusconaia cor *+		1	3	R	—	—	—	—	—	—	—	—	30	2
Fusconia cuneolus *+		—	—	R	—	—	—	—	—	—	—	—	2	0
Lampsilis fasciola		1	3	1	—	R	1	R	—	1	1	—	26	2
Lampsilis ovata		5	4	4	—	—	—	1	—	—	—	1	60	4
Lampsilis teres		—	—	—	—	—	—	—	—	—	—	—	4	0
Lampsilis virescens *+		—	—	—	—	—	R	1	—	—	—	—	1	0
Lasmigona complanata		—	—	—	—	—	—	—	—	—	—	—	R	0
Lasmigona costata		1	2	—	—	—	—	—	—	1	3	—	37	3
Lasmigona holstonia *		—	—	—	—	—	—	—	—	—	—	1	1	0
Leptodea fragilis		—	—	—	—	—	—	—	—	—	—	—	8	1
Lexingtonia dolabelloides *		3	124	10	—	2	5	—	7	12	5	2	309	23
Ligumia recta		—	—	—	—	—	—	—	—	—	—	—	1	0
Medionidus conradicus *		—	—	—	—	—	—	R	1	1	—	—	2	0
Megalonaias nervosa		—	—	—	—	—	—	—	—	—	—	—	47	3
Obliquaria reflexa		—	—	—	—	—	—	—	—	—	—	—	37	3
Obovaria subrotunda		—	7	1	—	—	—	—	—	—	—	—	9	1

Pleurobema cordatum	—	—	—	—	—	—	—	—	—	—	—	8	1
Pleurobema oviforme *	—	—	—	—	—	—	—	—	—	—	—	1	0
Potamilus alatus	1	—	—	—	1	—	—	—	—	1	—	103	8
Ptychobranchus fasciolaris	—	11	6	—	—	—	1	—	—	1	—	29	2
Quadrula cylindrica	—	13	10	—	—	—	—	—	—	4	—	40	3
Quadrula metanevra	—	—	—	—	—	—	—	—	—	—	—	4	0
Quadrula nodulata	—	—	—	—	—	—	—	—	—	—	—	1	0
Quadrula pustulosa	—	—	—	—	—	—	—	—	—	—	—	14	1
Quadrula quadrula	—	—	—	—	—	—	—	—	—	—	—	R	0
Toxolasma cylindrellus *+	—	—	—	—	—	—	—	1	—	R	—	1	0
Toxolasma lividus *	1	4	4	1	—	1	—	1	2	4	—	82	6
Tritogonia verrucosa	1	—	—	—	—	—	—	—	—	—	—	8	1
Truncilla donaciformis	—	—	—	—	—	—	—	—	—	—	—	R	0
Truncilla truncata	—	—	—	—	—	—	—	—	—	—	—	3	3
Villosa iris *	—	17	7	3	5	2	—	15	2	22	23	109	8
Villosa vanuxemensis *	—	8	5	—	4	3	—	2	1	8	2	81	6
Total number of mussels	15	197	49	4	13	12	17	27	22	77	37	1370	100
Total number of species	9	12	13	2	7	6	6	6	8	12	6		

* Cumberlandian species (12)
\+ Endangered species (4)
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TABLE 4. Individual measurements of federally listed endangered mussel species found during the freshwater mussel survey of the Paint Rock River system, July 1991.

Sites	River	Mile	Species	Length	Height	Thickness	Age
1	PRRM	13.3	*Fusconaia cuneolus*	46.3	39.3	26.6	13
2	PRRM	16.0	*Fusconaia cuneolus*	49.6	38.4	23.5	14
			Fusconaia cor	43.8	35.2	20.5	12
			Fusconaia cor	22.2	18.4	12.0	4
10	PRRM	43.1	*Fusconaia cor*	40.4	32.8	19.3	7
			Fusconaia cor	54.6	46.6	25.4	11
			Fusconaia cor	69.0	54.9	31.1	25+
			Fusconaia cor	71.4	55.4	28.3	25+
			Fusconaia cor	33.3	25.9	16.5	5
			Fusconaia cor	58.6	47.8	28.0	15
			Fusconaia cor	66.5	51.1	29.0	18
			Fusconaia cor	71.4	60.7	35.4	25
			Fusconaia cor	50.1	40.6	21.1	11
			Fusconaia cor	60.0	46.3	26.8	18
			Fusconaia cor	56.8	44.7	27.4	20
			Fusconaia cor	56.1	47.5	29.7	17
			Fusconaia cor	66.6	51.8	33.7	23
			Fusconaia cor	70.3	55.8	33.0	23
			Fusconaia cor	67.0	51.9	31.9	19
			Fusconaia cor	70.1	54.9	31.3	16
			Fusconaia cor	70.5	57.2	32.5	19
			Fusconaia cor	61.9	49.9	28.5	17
			Fusconaia cor	78.2	60.2	35.6	23
			Fusconaia cor	75.6	55.1	30.1	22
11	PRRM	44.8	*Fusconaia cor*	69.0	49.2	32.6	20+
13	PRRM	47.9	*Fusconaia cor*	66.3	50.8	28.7	18
14	PRRM	50.4	*Fusconaia cor*	72.7	61.7	39.0	30+
15	PRRM	51.4	*Fusconaia cor*	64.8	52.1	29.8	20+
16	PRRM	59.0	*Fusconaia cor*	40.1	30.9	18.7	12
			Fusconaia cor	41.3	31.0	19.8	12
			Fusconaia cor	48.2	36.8	19.3	14
21	EFRM	1.1	*Lampsilis virescens*	73.1	27.3	27.2	11
22	HCRM	0.1	*Toxolasma cylindrellus*	31.4	18.6	11.3	6

taining loose sand, mud, and silt. At sites 12, 14 and 21, blue-green algae covered the river substrate in shallow pools, and this was especially a problem in Estill Fork (site 21). At stream access fords the mussel fauna is depressed for a considerable distance downstream, suggesting severe impacts from possible spillage of agricultural chemicals during the filling of tank trucks used for spraying farm crops. Mussels were usually found upstream from access fords.

The Paint Rock River system was channelized in the mid-1960s and

riffle and shoal habitats have not stabilized. Shifting substrate is a problem in the drainage and probably a major factor affecting riffle-dwelling mussels, especially Cumberlandian species. Flooding is a also a problem in the drainage system. The Paint Rock River experienced close to a 100 year flood event in spring 1991 (Don Porter, TVA personal communication). As a result of the flood, live and dead mussels (including endangered species) were observed stranded in pools on top of gravel bars, and in many instances mussels and substrate were carried out of the streambed and deposited onto islands and shoal habitats. Streambanks were heavily scoured in some areas with no vegetation to keep the banks from collapsing. Cattle access has pockmarked and destabilized river substrate and streambanks at a number of sites, especially in Larkin and Estill Forks (sites 19 and 21), and Hurricane Creek (site 23). Cow manure was also observed covering river substrate in Hurricane Creek (site 23) and numerous dead shells of *Amblema plicata* were found in Estill Fork (site 21), upstream from the area where cattle frequent. Judging by the condition of relict shells, the mussels had been dead for a long time.

Commercial mussel fishermen harvest shell from the lower 40 miles of the Paint Rock River in search of commercially valuable washboards *(Megalonaias nervosa),* three-ridge *(Amblema plicata),* and pigtoes *(Pleurobema cordatum).* One landowner near Walker Mill Ford (site 9), reported mussel fishermen collecting shell from the river in late spring. Presently, the extent of musself ishing in the river is unknown.

Of the eight federally listed endangered species only four *(Fusconaia cor, F. cuneolus, Lampsilis virescens* and *Toxolasma cylindrellus)* were found. *Fusconaia cor* was the most numerous (14 live, 16 fresh-dead) and widespread in distribution. Of the total, twenty-one specimens (8 live, 13 fresh-dead) were found at site 10 in the Paint Rock. A long, shallow, unstable riffle extends upstream from a deep pool at this site. Streambanks in this area were characterized by deep cuts as a result of scouring from high-flows. This species was also found in low numbers from ten other sites in the Paint Rock with similar habitat conditions, and was not found in any of the tributary streams. Fusconaia cor is an endemic Cumberlandian riffle species, generally found in moderate to fast-flowing streams and rivers with stable substrate. The number of specimens found is encouraging, but persisting habitat perturbations threaten their continued survival. The fish hosts for *F. cor* have been tentatively identified as the common shiner *(Luxilus cornutus)* and whitetail shiner *(Cyprinella galactura)* (Kitchel, 1983; USFWS 1984b). Both fish species are present in the Paint Rock River (Charles Saylor, TVA, personal communication).

Fusconaia cuneolus was found in the lower Paint Rock with one live specimen from site 2 and one fresh-dead from site 1. Because of the rarity of this species in the river, it may be on the verge of extirpation from the Paint Rock. The single live specimen was found along the edge of water willow in unstable sand and gravel at the head of a shoal. *Fusconaia cuneolus* is closely related to *F. cor* and is also an endemic Cumberlandian riff le species typically found in moderate to fast-flowing streams which contain stable substrates (USFWS 1984c). The fish hosts for *F. cuneolus* are tentatively identified as fathead minnow *(Pimephales promelas),* river chub *(Nocomis micropogon),* central stoneroller *(Campostoma anomalum),* telescope shiner *(Notropis telescopus),* Tennessee shiner *(N. leuciodus),* white shiner *(Luxilus albeolus),* whitetail shiner *(Cyprinella galactura),* and mottled sculpin *(Cottus bairdi)* (Bruenderman 1989). At least three of these species (stoneroller, telescope shiner, and whitetail shiner) are present in the Paint Rock (Charles Saylor, TVA, personal communication).

Lampsilis virescens is an extremely rare mussel presently restricted to the Paint Rock River system. Historically in the Paint Rock, this species occurred in the upper mainstem, Estill and Larkin Forks, and Hurricane Creek (USFWS 1985b). One fresh-dead and one relict specimen was found in Estill Fork (sites 21 and 20). The fresh-dead specimen was observed stranded on a sandbar at the downstream end of a pool. *Lampsilis virescens* is an endemic Cumberlandian species which probably inhabits smaller tributary streams in pools containing sand or loose substrate. The species appears to have always been uncommon or rare wherever it occurred. The possibility exists that *L. virescens* may still survive in inaccessible reaches of upper Paint Rock tributaries; however, perturbations in these streams during recent years may have already reduced the only known extant population of this species to relict status. The life history for the species remains unknown.

One fresh-dead and one relict *Toxolasma cylindrellus* specimen was found at sites 22 and 24 in Hurricane Creek. Historically in the Paint Rock, this species occurred in the upper mainstem, Larkin and Estill Forks, and Hurricane Creek. This endemic Cumberlandian species inhabits smaller tributary streams and has always been considered uncommon or rare (USFWS 1984a). Stansbery (1976) reported collecting 26 shells of *T. cylindrellus* from a muskrat midden in Larkin Fork during 1966. This is the largest known collection of specimens reported for the species, and during that time, it may have been an indication of how common the species was in Larkin Fork before

channelization. Virtually nothing is known about the habitat requirements of *T. cylindrellus;* however, *T. lividus* overlaps in distribution and may live in similar habitat with *T. cylindrellus* in the Paint Rock. Numerous specimens of *T. lividus* were found living in pools, along the edge of water willow, and in sand or fine gravel in the stillwater zone along the very edges of the streambank almost out of the water. The fish host(s) for *T. cylindrellus* are unknown, but host species have been identified for *T. lividus* including, the longear sunfish *(Lepomis megalotis)* and green sunfish *(Lepomis cyanellus)* (Hill 1986). Both fish species occur in the Paint Rock (Charles Saylor, TVA, personal communication). The possibility exists that other populations of T. cylindrellus may still be present in inaccessible reaches of upper Paint Rock tributaries since the mussel is often associated with headwaters streams. However, because of stream perturbations, the continued survival of this species remains tenuous.

The remaining four federally listed endangered species *(Lampsilis abrupta, Epioblasma walkeri, Pleurobema plenum,* and *Villosa trabalis* were not found. Both *L. abrupta* and *P. plenum* are big river species which occasionally occur peripherally in larger tributaries (USFWS 1984d). Habitat is available for both species in the lower reaches of the Paint Rock and both may still be present. *Lampsilis abrupta* was first reported from the lower Paint Rock River in 1983 (USFWS 1985a), when one five-year-old specimen was collected fresh-dead from a muskrat midden. *Pleurobema plenum* was reported historically from the Paint Rock by Ortmann (1925) and has not been found since. A closely related big river species, *Pleurobema cordatum,* occurs in the lower Paint Rock and suggests that *P. plenum* may also continue to survive in the river since both species have overlapping distributions. *Pleurobema plenum, P. cordatum* and *L. abrupta* occur a short distance downstream in the impounded reaches of the Tennessee River (Wheeler Reservoir) as well, so host fish species have potential access to the lower Paint Rock. Fish host(s) for *P. plenum* are unknown; however, the sauger *(Stizostedion canadense)* is reported in the literature as one host for *L. abrupta* (Coker *et al.,* 1921).

The remaining two endangered Cumberlandian species that were not found in the Paint Rock River are *Epioblasma walkeri* (USFWS 1984e) and *Villosa trabalis* (USFWS 1984f). It is believed that both species no longer occur in the river, since no specimens or shell fragments were found. Freshwater mussels in the genus *Epioblasma* sp., many of which are endemic Cumberlandian riffle species, have suffered drastic declines because of poor water quality and habitat degradation

throughout their range during the last 50 years. Only one *Epioblasma* species *(E. triquetra)* was found (12 fresh-dead) specimens in the lower Paint Rock. This species is more widespread and not endemic in distribution but is becoming increasingly rare throughout it's range. Fish host(s) for *E. walkeri* are unknown.

Villosa trabalis is also believed extirpated from the Paint Rock although two *Villosa* species *(Villosa vanuxemensis* and *V. iris)* survive in the river system. Six fish species of darters *(Etheostoma virgatum, E. obeyense, E. olivaceum, E. kennicotti, E. simoterum* and *E. flabellare)* are identified as fish hosts for *V. trabalis* (Jim Layzer, USFWS, personal communication). Three of these fish species *(E. kennicotti, E. simoterum* and *E. flabellare)* are reported from the Paint Rock (Barr *et al.,* 1986).

Population Structure of Endangered Species

Lengths of 29 *Fusconaia cor* specimens measured ranged from 22.2 to 78.2 millimeters and included individuals in each ten millimeter interval between these extremes (Table 4). Age of specimens varied from 4 to 30# years with specimens in the 20-50 mm (4-11 years). This is an indication of limited reproduction in the Paint Rock. All measured specimens appeared healthy with excellent growth increments and no shell erosion.

Shell lengths and age of two (one live, one fresh-dead) of *Fusconaia cuneolus* were similar 49.6 mm (14 years) and 46.3 mm (13 years), respectively. Both individuals were in excellent condition showing good growth and little shell erosion. This species is presently restricted in distribution to the lower Paint Rock.

The remaining two endangered species, *Lampsilis virescens* and *Toxolasma cylindrellus,* were found only as single fresh-dead specimens. Shell length for *L. virescens* from Estill Fork was measured at 73.1 mm and aged at 11 years and *T. cylindrellus* reported from Hurricane Creek measured 31.4 mm in length and aged at 6 years. Both species appear near extirpation in these tributary streams.

SUMMARY

Forty-one mussel species were reported from the Paint Rock River system at 25 collecting sites. The most abundant species was *Lexingtonia dolabelloides,* followed by *Amblema plicata, Villosa iris* and *Potamilus alatus.* Deeper pools in the Paint Rock contained populations of *Cyclonaias tuberculata, Amblema plicata* and *Potamilus alatus.* Nineteen species were represented by five or fewer specimens, and three of these *(Lasmigona*

complanata, Quadrula quadrula and *Truncilla donaciformis)* were relicts. One species, *Lasmigona holstonia,* is a new record for this drainage.

Four of the eight federally listed endangered mussel species reported from the Paint Rock River system were found during the present survey. *Fusconaia cor* and *F. cuneolus* were both found alive only in the Paint Rock River. *Fusconaia cor* was the most abundant (30 specimens) and included ages ranging from 4 to 30 years. The two specimens of *F. cuneolus* were aged at 13 and 14 years. One fresh-dead specimen of *Lampsilis virescens* reported from Estill Fork was aged at 11 years and one fresh-dead specimen of *Toxolasma cylindrellus* found in Hurricane Creek was aged at six years. Both mussel species are extremely rare and may be on the verge of extirpation from these streams.

The mussel fauna and river habitat of the Paint Rock River system has not recovered from extensive stream channelization, snag removal, and riverbank clear-cutting in the mid-1960s. Substrate in riffles and shoals have not stabilized and in many instances flooding has resulted in deposition of mussels on islands or into depressions adjacent to river channels. Cattle access to the river and tributary streams is a problem because of streambank erosion and river substrate destabilization. At stream access fords the mussel fauna is depressed for a considerable distance downstream suggesting severe impacts from spillage of agricultural chemicals during the mixing with water in tank trucks. Mussels were usually found upstream from access fords, but not for a considerable distance downstream.

Because of nonpoint source pollution from agricultural land usage in the Paint Rock River system and destabilization of river substrate, riff le species are especially vulnerable. It appears that the mussel fauna is trying to make a recovery in the Paint Rock but is periodically affected by these activities. In general, the mussel fauna may continue to decline until appropriate measures are taken to minimize stream impacts.

ACKNOWLEDGEMENT

I would like to thank Dave Matthews and Mike Hansbrough, biological contractors with Fish and Wildlife Associates, Whittier, North Carolina, for their help in conducting this survey.

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STATUS SURVEY OF THE LITTLE-WING PEARLYMUSSEL, *PEGIAS FABULA* (LEA 1838)

Steven Ahlstedt[1,2] and Charles Saylor[1]

ABSTRACT — Mussel sampling for the Little-Wing Pearly Mussel, *Pegias fabula,* was initiated in July, 1984, under Memorandum of Agreement No. 14-16-004-84-927 between the United States Fish and Wildlife Service, Endangered Species Field Office, Asheville, North Carolina, and the Tennessee Valley Authority. The status survey was conducted to determine the species rarity and its possible candidacy for federal listing. Historically, this endemic species was considered rare and known from 24 stream reaches, all tributaries of the Tennessee and Cumberland river systems. Sites chosen for sampling were locations where the species had previously been documented. Extant populations were found to occur in the upper North Fork Holston (Tennessee River system) and the Little South Fork Cumberland River, Horse Lick Creek, and Cane Creek (Cumberland River system). Since completion of this study the species has been documented from the upper Clinch and Little Tennessee rivers, and the Big South Fork Cumberland River. The Little-Wing Pearly Mussel is extremely rare, and was federally listed in November 1988 as endangered.

Key words: Tennessee River, Cumberland River, Unionidae, *Pegias fabula.*

INTRODUCTION

The Tennessee and Cumberland River systems possess an extremely diverse freshwater mussel fauna. Included are many endemic forms characteristic of the Cumberland Plateau region, an area which encompasses portions of seven States bordering the southern Appalachian Mountains. This geographic area is considered an important center for mussel speciation, and endemic forms occurring in this region are referred to as Cumberlandian.

The U.S. Department of Interior presently lists 23 North American freshwater mussels as endangered; 13 of which are endemic to the Tennessee and Cumberland River drainage basins. The current status of the Little-Wing Pearly Mussel, *Pegias fabula,* an endemic Cumberlandian species, is presently being studied to determine if the species should remain on the Federal list of threatened and endangered species.

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DESCRIPTION

Pegias fabula was described by Isaac Lea (1838) as *Margaritana fabula* with the type locality "Cumberland River, Tennessee." The species is a member of the family Unionidae, subfamily Anodontinae. The subfamily includes two tribes: Anodontini and Alasmidontini (Morrison, 1956; Clarke & Berg, 1959; Clarke, 1981). The tribe Anodontini contains the genera *Anodonta, Anodontoides* and *Strophitus,* which are Holarctic in distribution and characterized by relatively thin, unsculptured shells with absent or rudimentary hinge teeth. The Nearctic tribe Alasmidontini contains nine genera including *P. fabula.* These genera are characterized by thickened shells, which may be sculptured, and the presence of pseudocardinal hinge teeth. Lateral teeth are developed in most species with an interdental projection (Clarke, 1981).

Pegias fabula (Fig. 1) attains a size of 35 mm long, 22 mm high and 12 mm wide (Simpson, 1914). Shells are thickened anteriorly, becoming relatively thin posteriorly with a sharp posterior ridge preceded by a wide radial depression that ends in a basal sinus. The anterior margin is semicircular and evenly rounded while the ventral margin is flatly curved anteriorly and straight or concave posteriorly. The posterior margin is bluntly pointed above the midline, obliquely truncated below, and angular or bluntly pointed again at its junction with the ventral margin. Beaks project slightly above the hinge line and are of moderate width, bluntly pointed, and located approximately one-third the distance from the anterior to posterior margin of the shell. Beak sculpturing consists of heavy, subconcentric ridges most prominent and persistent on the posterior ridges, but are usually obliterated in most specimens because of heavy shell abrasion. Growth rests are apparent but not gener-

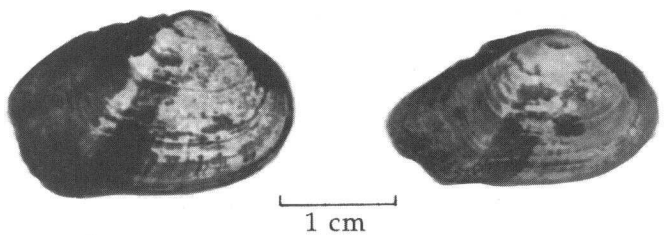

FIG. 1. *Pegias fabula* (Lea 1838), male (left), female (right). (Photo courtesy of Dr. Paul Parmalee, Frank H. McClung Museum, University of Tennessee, Knoxville).

ally strong, especially in older specimens. The periostracum is usually eroded giving a chalky or ashy white appearance. When present, the periostracum is light green or dark yellowish brown with broad to smaller dark rays apparent along the anterior portion of the shell. The hinge ligament is short, narrow, dark brown, and located immediately behind the umbo region. Hinge teeth are also well developed. The left valve has an irregular triangular pseudocardinal tooth, sometimes with the vestige of another tooth in front of it. Lateral teeth are short, vestigial, or entirely absent. The right valve has a single triangular pseudocardinal tooth in front of the beak. Beak cavities are deep and compressed with sunken anterior muscle scars. The nacre is whitish on the anterior border and usually salmon or flesh colored in the beak cavities (Simpson, 1914; Clarke, 1981; Bogan & Parmalee, 1983). The species is sexually dimorphic, a trait unknown in other species of alasmidontines (Simpson, 1900, 1914; Ortmann, 1914; Stansbery, 1976).

DISTRIBUTION

Historical

Lea (1838) first reported *"Margaritana" fabula* from the Cumberland River, Tennessee, and later (as *Margaritana curreyiana*) included the Stones River, a Cumberland River tributary near Nashville, Tennessee (Lea, 1840). Stansbery (1976) reported its former presence from Tennessee and Cumberland drainage streams in Virginia, Kentucky, Tennessee and Alabama. In the Cumberland River system, Stansbery included records as far downstream as the West Fork Red River, Todd County, Kentucky. Down-stream limit in the Tennessee River system appears to be Blue Water Creek, Lauderdale County, Alabama. All known records indicate a distribution limited to tributaries of the Tennessee and Cumberland River systems. Based on these records, *Pegias fabula* is strictly a Cumberlandian species endemic to the southern Appalachian Mountains and the Cumberland Plateau region (Ortmann, 1925). Historic and fossil records for this species are presented in Table 1.

LIFE HISTORY AND ECOLOGY

The life history of *Pegias fabula* is unknown, but is probably similar to other unionids in that a fish host is required for the species to

complete its reproductive life-cycle. Recent field observations indicate that the banded sculpin (*Cottus carolinae*) and the redline darter (*Etheostoma rufilineatum*) were observed nesting and/or hiding under large flat rocks and present on gravel shoals' where *P. fabula* was found. These fish may be candidate hosts for this species. Numerous crayfish also were observed under large rocks where specimens were found; however, crayfish have never been identified as hosts for freshwater mussels.

Gravid females reported in September and October indicate *Pegias fabula* is a winter or long-term brooder (bradytictic), holding glochidia from midsummer to spring of the following year (Ortmann, 1914; Starnes & Starnes, 1980; Clarke, 1981). During this study, gravid specimens were found laying on top of the substrate in late September in the North Fork Holston River (Smyth County, Virginia) and Horse Lick Creek (Rockcastle County, Kentucky). Nongravid or spawned females were also observed in Cane Creek (Van Buren County, Tennessee) in March 1986. In Cane Creek, specimens were buried into the substrate but were obtained by searching under flat rocks and digging into the substrate. This suggests the only time this species comes up out of the substrate is during spawning and probably accounts for the eroded shell condition of specimens observed.

Pegias fabula is known only from smaller, cool, high gradient tributary streams. As with almost all Cumberlandian mussel species, *P. fabula* is strictly a riffle species. Blankenship (1971), while sampling Horse Lick Creek, reported specimens laying on top of the substrate, free to be moved by churning water. Starnes & Starnes (1980) reported specimens in the Little South Fork Cumberland River either partly buried or on top of the substrate in the transition zone between a long pool and riffle. Di Stefano (1984) reported six specimens from Horse Lick Creek buried in gravel and sand substrate, and under large rocks.

Wilson & Clark (1914) considered the species rare after collecting only two live specimens during an extensive survey of the Cumberland River drainage. The rarity of the species throughout historic and recent times may be attributed to it being overlooked due to its small size and often eroded condition, or its occurrence in high gradient streams located in inaccessible areas. An additional factor may be the short time (spawning period) when specimens are near the substrate surface where they can be observed. This phenomenon has been observed for other rare or uncommon mussel species which were found to be less rare than was previously thought (Ahlstedt, 1991a).

Further, most mussel surveys are conducted during low flow periods in warm water conditions (summer or early fall). Using wet suits while sampling for mussels in water temperatures between 50° and 70°F during late spring (May and June) and late fall (October and November) has yielded numerous species that were observed partially buried or laying on top of the substrate spawning (*e.g., Quadrula intermedia, Q. sparsa, Dromus dromas, Epioblasma capsaeformis, E. brevidens*). Resampling those same locations during warmer water conditions has yielded fewer specimens, and then only after extensive digging.

METHODS AND MATERIALS

Because of widespread distribution and limited funding, sampling for *Pegias fabula* occurred at locations where the species had been reported since the mid-1960s. Those sites were examined first to (1) update these records, (2) determine habitat requirements, and (3) refine species-specific sampling techniques. A number of streams within the species geographic range were not searched because mussel surveys conducted in the late 1970s and early 1980s did not include records of the species. Some smaller streams previously unsampled were searched in hopes of finding new populations. A list of collection sites, including totals for all mussel species found, is presented in the Appendix (Table A-1).

Field sampling was conducted at various dates between June 1984 and March 1986 during clear, low-flow conditions. Many of the streams sampled were too shallow to float-survey due to small size and drought conditions; therefore, sampling was conducted at locations accessible by road. Each set of locality data was taken from 1:24,000 topographic maps and consisted of the following: stream name, landmark, date, river mile or highway location, county, and state. Shoal (riffle) and pool areas were sampled by snorkeling. All small mussels observed were removed from the substrate, sorted and identified. Larger mussels observed were often not collected because of the single purpose of the survey. Occasionally, a garden rake was used to disturb gravel and sand substrates and then searched for exposed mussels.

At sites where live *Pegias fabula* were found, 10 random square-meter quadrat samples were collected to provide population estimates. Quantitative sampling consisted of placing a metal square-meter sampling frame on top of the substrate. Starting from the downstream edge of the sample frame, all rocks and rubble were removed from the area down to a depth of 76 mm. All substrates were searched for mussels (including *Corbicula fluminea* and *Sphaerium* sp.); animals found were sorted, identified, counted, and recorded on field data sheets. (Large numbers of *C. fluminea* in Little South Fork Cumberland River precluded counts of that species.) Voucher specimens were preserved in 10% formalin and taken to the TVA fisheries laboratory in Norris, Tennessee, for cleaning, verification and storage. No live federally listed endangered mussels were taken as voucher specimens. Voucher specimens were deposited with the Academy of Natural Sciences, Philadelphia, Pennsylvania.

In addition to instream sampling, streambanks were searched for shell middens. All fresh-dead shells (*i.e.*, evidence of flesh attached to the shell and/or shiny nacre with hinge ligament intact) were identified in the field, recorded on field data sheets, and placed in cloth collecting bags with an appropriate field identification label.

Museum records for *Pegias fabula* cited in this report (Table 1) were extrapolated from published reports and personal contacts with field biologists and museum cura-

tors. Records cited represent the most current information available on the distribution of this species.

RESULTS AND DISCUSSION

Since the early 1970s, live specimens of *Pegias fabula* were known from only one tributary stream in the Tennessee River drainage and four streams in the Cumberland River system. Eight live specimens were reported from the upper North Fork Holston River at Nebo, Virginia (Stansbery, 1972; Stansbery & Clench, 1974; Clarke, 1981), and one live specimen was found in the North Fork Holston River at Broadford, Virginia, in 1984 (Dr. Richard Neves, Virginia Polytechnic Institute and State University at Blacksburg, Virginia, personal communication). To date, these are the only records of the species from the Tennessee River system, aside from relict or subfossil specimens (Table A-1).

In recent years, tributaries of the Cumberland River contained the largest extant populations of *Pegias fabula.* Specimens have been reported from the Little South Fork Cumberland River, Rockcastle River, Horse Lick Creek, and Buck Creek. The lower 21 km of the Little South Fork reported the largest population at Freedom Church Ford and Ritner Ford (Starnes & Starnes, 1980; Starnes & Bogan, 1982). Live specimens were also found in the Rockcastle River and lower 14 km of Horse Lick Creek, a tributary to the Rockcastle River (Blankenship, 1971; Blankenship & Crockett, 1972; Harker *et al.,* 1980; Di Stefano, 1984; Glen Fallo, Eastern Kentucky University at Richmond, personal communication). In 1983, Fallo collected one live specimen approximately three km above the mouth of Horse Lick Creek. Recently, Thompson (1985) searched extensively throughout the Rockcastle River system including the Middle and South Forks without finding a single specimen of *P. fabula.* During the present study, one relict shell was found in the Rockcastle approximately three km above the confluence of Horse Lick Creek.

Stansbery (1976) collected one live specimen of *Pegias fabula* from Buck Creek at Stab, Kentucky, in 1974. Recent sampling in Buck Creek during this investigation at four sites (Kentucky routes 461, 39, and 70 bridge crossings) failed to locate any specimens. Additional mussel sampling throughout Buck Creek by Eastern Kentucky University students (Dr. Schuster, Eastern Kentucky University at Richmond, personal communication) have also failed to produce any evidence of its continued survival in this stream.

Robert Butler (Eastern Kentucky University at Richmond, personal

communication) found fossil specimens of *Pegias fabula* in Pittman Creek during summer 1984. During this study, Pittman Creek near Somerset, Kentucky, was sampled at five sites but no specimens were found (Table A-1).

Herb Athearn (Cleveland, Tennessee, personal communication) reported live specimens of *Pegias fabula* in the mid-1960s from the Collins River at Shellsford Bridge and Irving College near McMinnville, Tennessee, and Cane Creek at Sweetgum where a large number (38) of specimens were reported. All three sites were intensively sampled during the present study with live specimens found only in Cane Creek.

Based on museum records and published surveys, this species was historically reported from Wallen Creek, tributary to the Powell River; Valley Creek, tributary to the Watauga River; and Blue Water Creek, tributary to the lower Tennessee River (Ortmann, 1918, 1925; Stansbery, 1976; Dr. Arthur Bogan, personal communication, 1985). Recent sampling in each of these streams found no evidence of its continued existence.

Recent sampling by a number of individuals have failed to find additional populations of *Pegias fabula* from the following Tennessee River tributaries: Elk River (Ahlstedt 1983, 1991b), Duck River (Ahlstedt, 1981, 1986), Powell River (Neves *et al.*, 1980; Ahlstedt & Brown, 1980, 1991b; Dennis, 1981, 1985), Clinch River (Stansbery, 1973; Bates & Dennis, 1978; Neves *et al.*, 1980; Dennis, 1985; Ahlstedt, 1991a), Copper Creek (Ahlstedt, 1981), South and Middle Forks Holston River (Stansbery & Clench, 1978; Neves *et al.*, 1980; Dennis, 1985), Holston River (Ahlstedt, 1991b), and Big Mocassin Creek (Neves & Sale, 1982; Dennis, 1985). In the Cumberland River system it is believed extirpated from the Rockcastle River (Thompson, 1985), Buck Creek (Dr. Schuster, personal communication 1985), Pittman Creek, (Robert Butler, personal communication), Stones River (Schmidt, 1982), and Collins River (Herb Athearn, personal communication 1985).

As a result of this survey, live and fresh-dead specimens of *Pegias fabula* were found only in the upper North Fork Holston River above Nebo, Virginia (Fig. 2), Little South Fork Cumberland River at Kidds Ford Crossing, Kentucky (Fig. 3), Horse Lick Creek, Kentucky (Fig. 4), and Cane Creek at Sweetgum, Tennessee (Fig. 5).

Sampling in the upper North Fork Holston at seven sites produced six specimens of *Pegias fabula* (three live, one fresh-dead, and two relicts) at route 622 bridge above Nebo. The single female collected was gravid. A total of 10 square-meter quadrat samples was taken to determine density estimates; however, no specimens were found (Ap-pendix A).

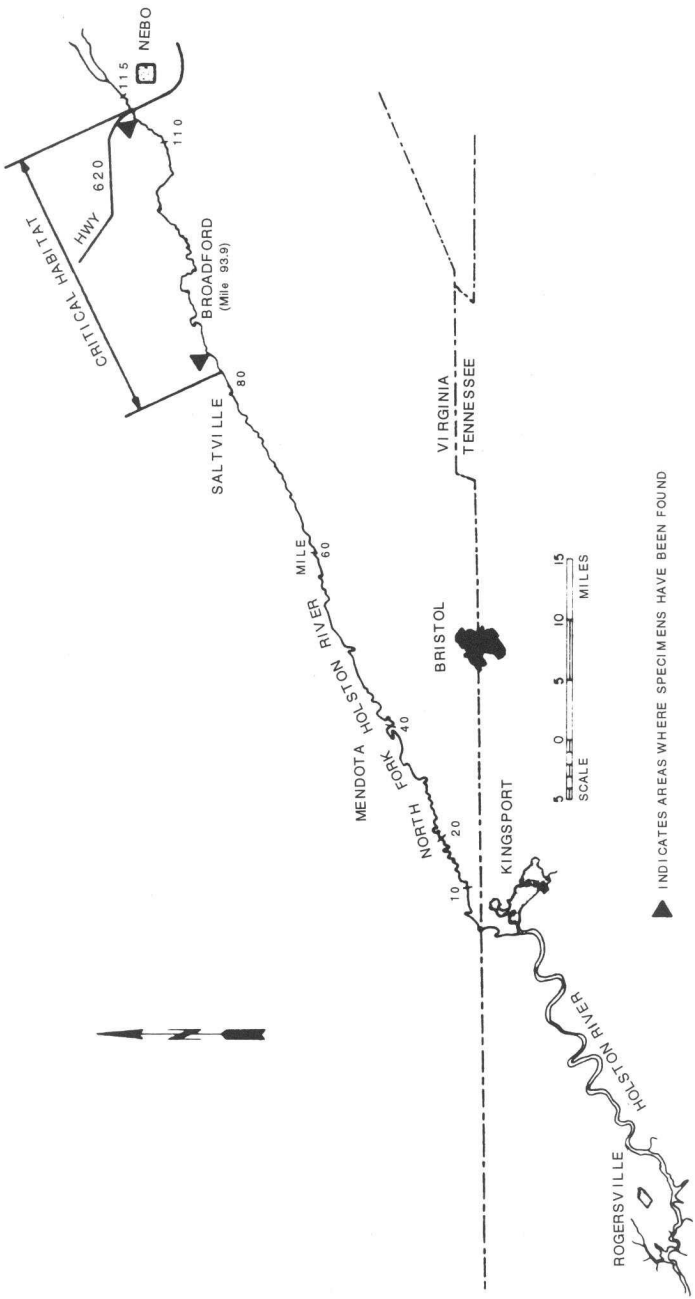

FIG. 2. North Fork Holston River - locations where *Pegias fabula* was found.

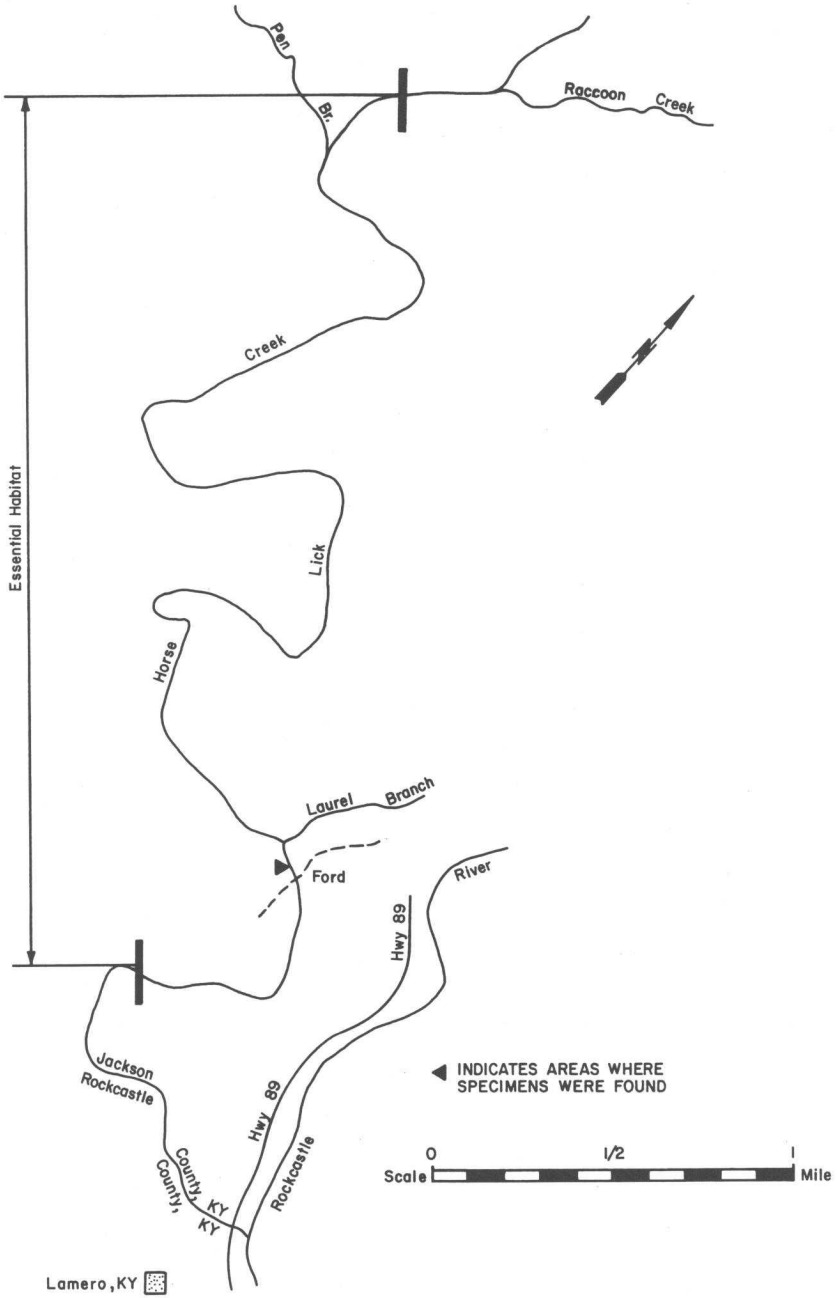

FIG. 3. Horse Lick Creek - locations where *Pegias fabula* was found.

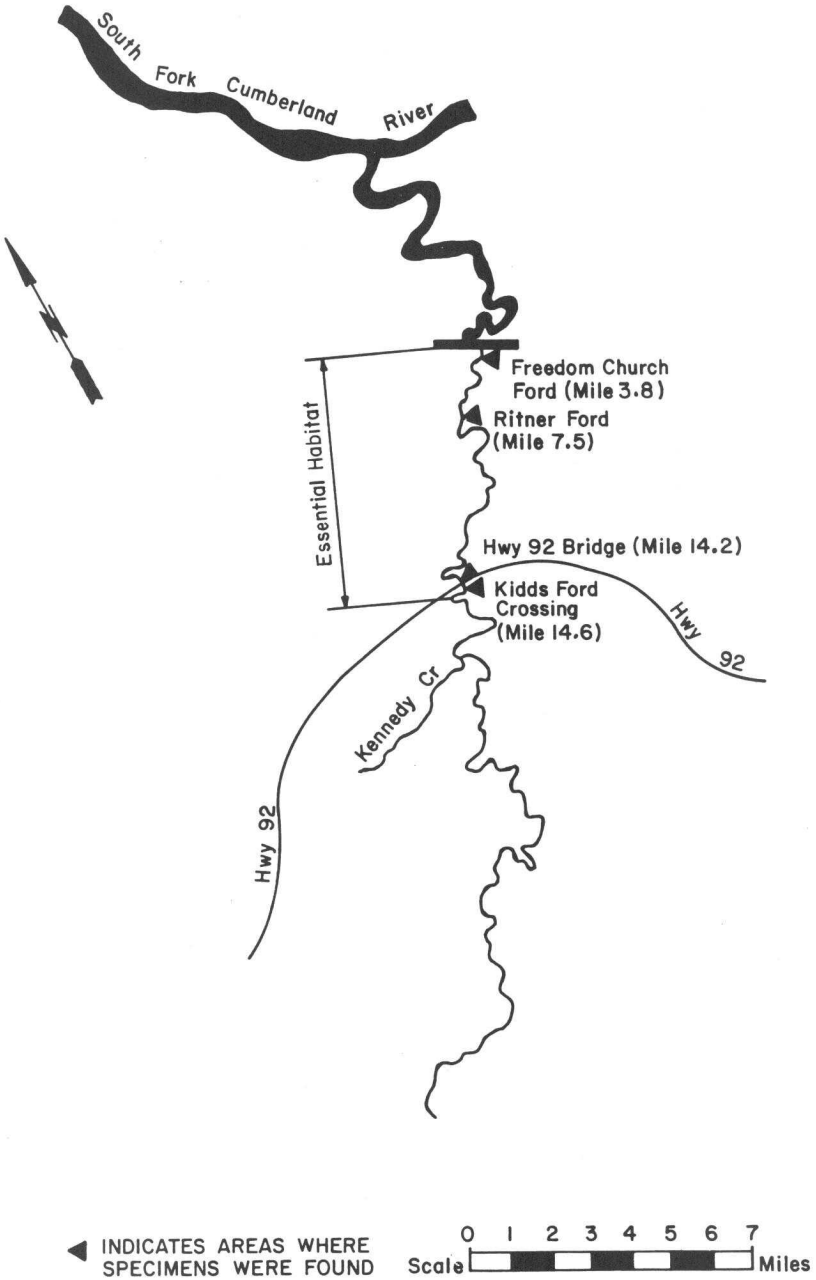

FIG. 4. Little South Fork Cumberland River - locations where *Pegias fabula* was found.

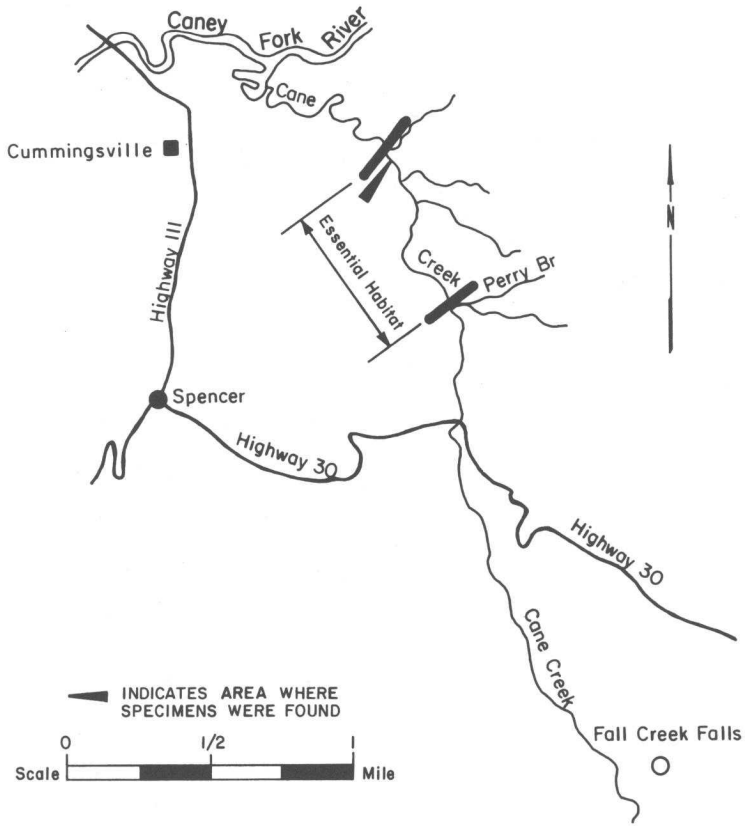

FIG. 5. Cane Creek – locations where *Pegias fabula* was found.

The Little South Fork Cumberland River was sampled at four sites in 1984 and 1985, including Kidds Ford Crossing, route 92 bridge, aged at six years by counting annual growth rests on the external surface of the shell. This suggests both specimens had reproduced successfully within the last six to eight years. The large number of live specimens found in Horse Lick Creek and Cane Creek is probably an indication that both creeks support reproducing populations.

Since the completion of this status survey three additional locations have been discovered for the species. In May 1986, during a survey of the freshwater mussel fauna in the Big South Fork Cumberland River, a large number of individuals (20 live, 18 fresh-dead) were found at mile 52.7 upstream from Oil Well Branch in McCreary County, Kentucky (Steve Bakaletz, personal communication). This is the first report of this species from the Big South Fork. Bakaletz reported find-

ing specimens under large slab rocks in clean swept riffles. This species was reported also from the upper Clinch River, approximately one-half mile downstream from route 639 bridge crossing in Tazewell County, Virginia (Dr. Richard Neves, personal communication). The single live specimen was collected in February 1987 by graduate students conducting a mussel survey of the area. This species was found in clean swept rubble and gravel habitat. The last report of this species occurrence in the Clinch was a single subfossil specimen collected in 1968 (Stansbery, 1976). One fresh-dead specimen was collected in the upper Little Tennessee River by Richard Biggins, USFWS, Ashville, North Carolina, who was collecting with the author and Mark Gordon, Tennessee Technological University, Cookville, Tennessee in 1990. This is the first report of the species in the upper Little Tennessee River.

CONCLUSIONS

Populations of *Pegias fabula* in the upper North Fork Holston River appear to have changed little since the 1970s; however, this small population is largely limited to one site. Given the small stream size of the upper North Fork and its remote location, potential problems appear to be limited to increased logging, oil and gas exploration, and overcollecting. Muskrat predation is probably not a problem since this species is often found under large rocks and is generally inaccessible to this predator. Recent conversations with Jerry Fouse, Virginia Commission of Game and Inland Fisheries, revealed no Federal project permits have been issued for activities that would affect the upper North Fork Holston.

Extant populations in the Cumberland River drainage (Horse Lick Creek, Little South Fork Cumberland River, and Cane Creek) are also situated in remote, mountainous terrain away from urban development. However, Horse Lick Creek and the Little South Fork Cumberland River may be impacted by activities associated with coal mining. Silt and acid mine drainage from strip mining, deep mining, abandoned mined lands, and oil and gas exploration could cause major changes in both watersheds within the next few years. Horse Lick Creek, located in Daniel Boone National Forest, presently contains the largest population of the species. The creek is considered one of Kentucky's outstanding resource waters; however, strip mining is already in progress in the Clover Bottom area of the watershed. All known locations for Pe*gias fabula* occur downstream from mined areas. Increased mining and/or acid water runoff could seriously impact

these populations. Although no Federal projects are identified in the Horse Lick Creek watershed, logging, oil and gas exploration, and overcollecting are considered potential problems.

Approximately 16 km of the lower Little South Fork Cumberland River is designated Kentucky State wild river. When this portion of the river was searched for *Pegias fabula,* large numbers of mussels were observed dead. Sherri Evans of the Kentucky Division Water Resources (personal communication) reported acid water and silt from active and abandoned strip mines enter the Little South Fork along the lower portions of the river. She also noted leakage from settling ponds filled with silt during this survey. Lick Creek, a tributary stream located at Ritner Ford, was covered with a white substance which was later identified as aluminum flocculent. No fish or aquatic invertebrates were observed in this creek. Rust colored "yellow boy" from mine sites in the watershed was observed in smaller streams. Recently, new strip mines have been approved for the Little South Fork watershed (Evans, personal communication). Increased strip mining (silt and acid water runoff) is considered an imminent threat to this species in the Little South Fork. No Federal projects are identified in the watershed, but logging, oil and gas exploration, and overcollecting are considered additional potential problems.

Pegias fabula populations in Cane Creek appear restricted to the lower five km of the creek above the impounded backwaters of the Caney Fork River (Center Hill Reservoir). Mussel habitat is extremely limited in the stream because of impoundment, the predominance of large round boulders typical of mountain streams, and the absence of gravel and sand shoals. Because of its restricted distribution and limited habitat in Cane Creek, road and bridge construction and overcollecting are considered major problems for the species.

Essential Habitat

Habitats considered essential for the continued survival of *Pegias fabula* are those areas where the species presently occurs: upper North Fork Holston River, Horse Lick Creek, lower Little South Fork Cumberland River, and Cane Creek. A more detailed description of each area is presented below:

North Fork Holston River - above Saltville (NFHRM 85), upstream to county route 620 bridge crossing at Nebo (NFHRM 111.6), Smyth County, Virginia (Fig. 2).

Horse Lick Creek - at unnamed ford (HLCM 2.0), Jackson and Rockcastle Coun-

ties, Kentucky, upstream to below mouth of Raccoon Creek (HLCM 5.3), Jackson County, Kentucky (Fig. 3).

Little South Fork Cumberland River - from Freedom Church Ford (LSFCRM 3.8), upstream to Kidds Ford Crossing (LSFCRM 14.6) upstream from route 92 bridge, Wayne and McCreary Counties, Kentucky (figure 4).

Cane Creek - at Sweetgum off county road 4251, shoal upstream of swinging bridge, to mouth of Perry Branch near Cane Creek Church, Van Buren County, Tennessee (Fig. 5).

MANAGEMENT AND RECOVERY

Management and recovery of *Pegias fabula* are almost totally dependent on funding available through State and Federal agencies. Actions deemed necessary or essential for the continued survival of the species are presented in recovery plans of other federally listed endangered mussel species. Recovery actions considered essential for the survival of this species are listed below in order of priority:

1. Immediate protection of all existing populations to include any new populations discovered.
2. Identify present and foreseeable threats to the species and its habitat, and work to eliminate them.
3. Conduct life history studies and determine host fish species.
4. Investigate the use of an artificial culture medium for mass propagation.
5. Identify potential transplant sites in streams within the species historical range.
6. Transplant juveniles or infected host fish into selected stream reaches.
7. Develop and implement a program to monitor the success of transplants, and evaluate recovery.

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APPENDIX A

TABLE A-1. Location of collecting sites and number of mussel specimens found. Species marked with an asterisk (*) are endangered.

Tennessee River Drainage

Little River - tributary to upper Clinch River at mile 299.6 downstream from route 19 bridge crossing at Wardell, Tazewell County, Virginia. September 14, 1985.

No live or relict mussels found.

Little River - tributary to upper Clinch River at route 610 bridge crossing above Greens Chapel, Tazewell County, Virginia. September 14, 1985.

Villosa iris - 4

Upper Clinch River - upstream from route 639 bridge crossing near Cliffield, Tazewell County, Virginia. September 13, 1985.

Fusconaia barnesiana - 46
Lampsilis fasciola - 1
Medionidus conradicus - 49
Villosa iris - 399
Sphaerium - common
Numerous young *Villosa iris*

Upper Clinch River - at route 640 bridge crossing upstream from Cedar Bluff,

Tazewell County, Virginia. September 15, 1985.

Fusconaia barnesiana - 2
Lampsilis fasciola - 1
Medionidus conradicus - 9
Villosa iris - 119
Villosa vanuxemensis - 1
Sphaerium - common

Upper Clinch River - downstream from Taylor Mill Dam, Tazewell County, Virginia. September 13, 1985.

Fusconaia barnesiana - 4
Villosa iris - 11

Middle Fork Holston River - downstream from bridge at Chilhowee, Smyth County, Virginia. September 10, 1985.

Elliptio dilatata - 20
**Epioblasma florentina walkeri* - 5
Fusconaia barnesiana - 2
Lampsilis fasciola - 2
Lexingtonia dolabelloides - 2
Medionidus conradicus - 2
Pleurobema oviforme - 6
Ptychobranchus subtentum - 4
Villosa iris - 5
Villosa vanuxemensis - 73

Laurel Creek - tributary to upper North Fork Holston River at route 91 bridge crossing, 2.7 miles upstream from mouth, Tazewell County, Virginia. September 11, 1985.

Villosa iris - 2

North Fork Holston River - at river mile 85.2 above Saltville, Smyth County, Virginia. September 11, 1985.

Fusconaia barnesiana - 1
Medionidus conradicus - 4
Toxolasma lividus - 2 relicts
Villosa vanuxemensis - 1

North Fork Holston River - at river mile 93.3 upstream from mouth of Laurel Creek, Smyth County, Virginia. September 11, 1985.

Actinonaias pectorosa - 35
Alasmidonta viridis - 2
Fusconaia barnesiana - 27
**Fusconaia cor* -32

Lampsilis fasciola - 47
Lexingtonia dolabelloides - 217
Medionidus conradicus - 68
Pleurobema oviforme - 1
Ptychobranchus fasciolaris - 19
Ptychobranchus subtentum - 17
Villosa iris - 101
Villosa vanuxemensis - 85

North Fork Holston River — at river mile 96.1 off route 42 near unnamed island, Smyth County, Virginia. September 9, 1985.

Actinonaias pectorosa - 2
Fusconaia barnesiana - 1
Lampsilis fasciola - 2
Lexingtonia dolabelloides - 4
Ptychobranchus fasciolaris - 1
Ptychobranchus subtentum - 11

North Fork Holston River - at bridge one-fourth mile southwest of Chatham Hill, Smyth County, Virginia. September 11, 1985.

Fusconaia barnesiana - 2
Lampsilis fasciola - 2
Medionidus conradicus - 1
Villosa iris - 9
Villosa vanuxemensis - 9

North Fork Holston River - at mouth of McDonald Branch Creek downstream from Nebo, Smyth County, Virginia. September 11, 1985.

No mussels observed.

North Fork Holston River - downstream from route 622 bridge above Nebo, Smyth County, Virginia. September 12, 1985.

Medionidus conradicus - 8
Pleurobema oviforme - 27
Pegias fabula - 3 live, 1 fresh-dead, 2 relict
Villosa iris - 48
Sphaerium - common

Quantitative sampling

1. *Pleurobema oviforme* - 1
   Villosa vanuxemensis - 3
   Sphaerium - 7
2. *Sphaerium* - 1
3. *Fusconaia barnesiana* - 2
   Sphaerium - 1
4. *Fusconaia barnesiana* - 1
   Villosa iris - 1

Villosa vanuxemensis - 1
5. *Villosa vanuxemensis* - 1
6. *Villosa iris* - 1
   Villosa vanuxemensis - 1
   Sphaerium - 1
7. *Sphaerium* - 3
8. *Fusconaia barnesiana* - 1
9. *Fusconaia barnesiana* - 1
10. *Villosa iris* - 2
    Villosa vanuxemensis - 1
    Sphaerium - 5

North Fork Holston River - at route 610 bridge crossing downstream from Groseclose store, Bland County, Virginia. September 12, 1985.

Fusconaia barnesiana - 9
Villosa vanuxemensis - 36
Sphaerium - abundant

Wallen Creek - tributary to upper Powell River approximately two miles downstream from Thompson Mill Dam off route 665, Lee County, Virginia. April 23, 1985.

Fusconaia barnesiana - 1
Medionidus conradicus - 2
Villosa iris - 18
Villosa vanuxemensis - 3

Wallen Creek - off route 665 downstream from Thompson Mill Dam, Lee County, Virginia. April 23, 1985.

No mussels observed.

Valley Creek - tributary to upper Watauga River, at junction of creek and Watauga River, Watauga County, North Carolina. February 4, 1986.

No mussels observed.

Watauga River - at Foscoe, Watauga County, North Carolina. February 4, 1986.

No mussels observed.

Watauga River - one-half mile downstream from Foscoe, Watauga County, North Carolina. February 4, 1986.

No mussels observed.

Watauga River - one mile downstream from junction of route 105 and county road 1112. February 4, 1986.

No mussels observed.

Watauga River - at bridge approximately one mile below Valle Crucis, Watauga

County, North Carolina. February 4, 1986.

No mussels observed.

Watauga River - at junction of Cane Creek and Watauga River, Watauga County, North Carolina. February 4, 1986.

No mussels observed.

Blue Water Creek - at route 72 bridge crossing near Elgin, Lauderdale County, Alabama. March 5, 1986.

No mussels observed.

Blue Water Creek - at route 71 bridge crossing, Lauderdale County, Alabama. March 5, 1986.

No mussels observed.

Blue Water Creek - at route 64 bridge crossing, Lauderdale County, Alabama. March 5, 1986.

No mussels observed.

Cumberland River Drainage

Collins River - at Shellsford Bridge, Warren County, Tennessee. June 20, 1984.

Pleurobema gibberum - 27
Villosa iris - 53

Collins River - near Irving College, Warren County, Tennessee. June 20, 1984.

Pleurobema gibberum - 12
Villosa iris - 23

Cane Creek - tributary to the Caney Fork River at Perry Branch near Cane Creek Church, Van Buren County, Tennessee. March 4, 1986.

Villosa iris - 21

Cane Creek - tributary to the Caney Fork River at shoal immediately upstream of swinging bridge at Sweetgum, off route 4251, Van Buren County, Tennessee. March 4, 1986.

Alasmidonta marginata - 1
Medionidus conradicus - 1 relict
Pegias fabula - 4 live, 2 fresh-dead, 2 relict
Pleurobema gibberum - 2 fresh-dead
Villosa iris - 20 (common)

Fishing Creek - tributary to Cumberland River downstream from route 70

bridge crossing, Pulaski County, Kentucky. September 27, 1985.

No mussels observed.

Fishing Creek - upstream from route 635 bridge crossing, Pulaski County, Kentucky. April 20, 1985.

No mussels observed.

Rockcastle River - one mile downstream from Livingston, Rockcastle County, Kentucky. September 24, 1985.

Actinonaias pectorosa - 2
Amblema plicata - 1 relict
Cyclonaias tuberculata - 2 relict
Elliptio dilatata - 11
Lampsilis ovata - 1
Ligumia recta - 4
Tritogonia verrucosa - 1

Rockcastle River - downstream from route 490 bridge crossing, one mile southeast of Lamero, Rockcastle and Laurel Counties, Kentucky. September 24, 1985.

Actinonaias ligamentina - 2
Actinonaias pectorosa - 3
Amblema plicata - 6
Elliptio dilatata - 14 (numerous)
Fusconaia subrotunda - 2
Lampsilis fasciola - 2
Lampsilis ovata - 3
Lasmigona costata - 3
Ligumia recta - 2
Potamilus alatus - 1
Ptychobranchus fasciolaris - 5
Tritogonia verrucosa - 2
Villosa iris - 1

Rockcastle River - two miles upstream from Horse Lick Creek off route 89 at canoe launch, Jackson and Laurel Counties, Kentucky. September 25, 1985.

Actinonaias pectorosa - 1
Elliptio dilatata - 3
Lampsilis ovata - 1
Ligumia recta - 1
Medionidus conradicus - 5
Pegias fabula - 1 relict
Ptychobranchus fasciolaris - 1
Ptychobranchus subtentum - 1
Villosa taeniata - 13

Skegg Creek - tributary to Rockcastle River upstream from Interstate 75 bridge

crossing, Rockcastle and Laurel Counties, Kentucky. September 27, 1985.

No mussels observed.

Horse Lick Creek - tributary to Rockcastle River approximately two miles upstream from mouth, Rockcastle and Jackson Counties, Kentucky. September 24, 1985, and December 17, 1985.

Alasmidonta marginata - 1
Actinonaias pectorosa - 1
Elliptio dilatata - 19
Lampsilis ovata - 1
Lasmigona costata - 1
Medionidus conradicus - 8
Pegias fabula - 7 live, 1 fresh-dead, 2 relict
Ptychobranchus fasciolaris - 1
Ptychobranchus subtentum - 2
Toxolasma lividus - 1
Villosa iris - 22

Quantitative sampling

1. *Corbicula fluminea* - 3
2. *Corbicula fluminea* - 4
3. *Alasmidonta viridis* - 1
   Villosa taeniata - 1
   Sphaerium - 12
   Corbicula fluminea - 20
4. *Sphaerium* - 1
   Corbicula fluminea - 6
5. *Corbicula fluminea* - 14
6. *Corbicula fluminea* - 9
7. *Corbicula fluminea* - 3
8. *Corbicula fluminea* - 1
9. No mussels
10. No mussels

Roundstone Creek - tributary to Rockcastle River at Sinks, Rockcastle County, Kentucky. September 25, 1985.

Elliptio dilatata - 1 relict
Lampsilis fasciola - 1 relict
Villosa iris - 1 relict
* *Villosa trabalis* - 2 relicts
Corbicula fluminea - abundant

Roundstone Creek - downstream from railroad bridge at Hummel, Rockcastle County, Kentucky. September 24, 1985.

Lampsilis ovata - 1 relict
Lampsilis fasciola - 1
* *Villosa trabalis* - 1 relict

Towne Creek - tributary to Roundstone Creek near Hummel Road bridge, Rockcastle County, Kentucky. September 25, 1985.

Alasmidonta viridis - 1 relict
Villosa iris - 3 relicts
Corbicula fluminea - abundant

Pittman Creek - at route 1247 bridge crossing near Elihu, Pulaski County, Kentucky. September 13, 1984.

No mussels observed.

Pittman Creek - at route 769 bridge crossing at Alcalde, Pulaski County, Kentucky. September 13, 1984.

No mussels observed.

Pittman Creek - at route 192 bridge crossing at Ruth, Pulaski County, Kentucky. September 13, 1984.

No mussels observed.

Pittman Creek - tributary to Cumberland River at route 39 bridge crossing near Somerset, Pulaski County, Kentucky. September 14, 1984.

No mussels observed.

Pittman Creek - at route 452 bridge crossing near Pulaski, Pulaski County, Kentucky. September 14, 1984.

No mussels observed.

Buck Creek - upstream from route 80 bridge crossing at Stab, Pulaski County, Kentucky. November 14, 1984.

Lampsilis fasciola - 1
Lampsilis ovata - 1
Villosa iris - 3 relicts
**Villosa trabalis* - 2 relicts

Buck Creek - below highway to bridge crossing at Briary Creek, Pulaski County, Kentucky. November 13, 1984.

Lampsilis fasciola - 1 relict
Lampsilis ovata - 1 fresh-dead, 1 relict
Medionidus conradicus - 1 relict
Obovaria subrotunda - 1 fresh-dead
Potamilus alatus - 1 fresh-dead
**Villosa trabalis* - 1 relict

Buck Creek - downstream from route 39 bridge crossing above Bobtown, Pulaski

County, Kentucky. November 13, 1984.

Lampsilis ovata - 3 relicts
Potamilus alatus - 2 relicts
**Villosa trabalis* - 2 relicts

Buck Creek - downstream from route 461 bridge crossing, Pulaski County, Kentucky. September 26, 1985.

Elliptio dilatata - 3
Epioblasma brevidens - 1
Lampsilis fasciola - 3
Lampsilis ovata - 2
Medionidus conradicus - 1
Obovaria subrotunda - 1
Potamilus alatus - 2
Ptychobranchus fasciolaris - 2
Villosa iris - 11
**Villosa trabalis* - 5 fresh-dead, 4 relicts

Little South Fork Cumberland River - at river mile 14.6 located upstream of route 92 bridge crossing at Kidd's Ford Crossing, Wayne and McCreary Counties, Kentucky. November 15, 1984, and April 20, 1985.

Alasmidonta marginata - 2 fresh-dead
Elliptio dilatata - 2 fresh-dead
Fusconaia barnesiana - 1 fresh-dead
Lampsilis fasciola - 2 fresh-dead, 1 relict
Lampsilis ovata - 1 fresh-dead
Lasmigona costata - 2 fresh-dead
Medionidus conradicus - 1 fresh-dead, 1 relict
Obovaria subrotunda - 14 fresh-dead
Pegias fabula — 3 live, 72 fresh-dead and relict
Pleurobema oviforme - 1 live, 11 fresh-dead, 1 relict
Potamilus alatus - 2 fresh-dead
Ptychobranchus fasciolaris - 3 fresh-dead
Ptychobranchus subtentum - 7 fresh-dead, 2 relict
Toxolasma lividus - 13 fresh-dead, 1 relict
Villosa iris - 7 fresh-dead
Villosa taeniata - 2 fresh-dead, 11 relict
**Villosa trabalis* - 11 fresh-dead, 2 relict

Kennedy Creek - approximately 100 yards upstream from mouth of creek draining into Little South Fork Cumberland River, Wayne County, Kentucky. April 18, 1985.

Pegias fabula - 3 relicts
Pleurobema oviforme - 2 fresh-dead
**Villosa trabalis* - 1 fresh-dead

Kennedy Creek - off route 92 at unnamed ford, Wayne County, Kentucky. April 18, 1985, and April 19, 1985.

No mussels observed.

Little South Fork Cumberland River - at Ritner Ford, river mile 7.5, Wayne and McCreary Counties, Kentucky. November 14, 1985.

Alasmidonta marginata - 1 fresh-dead
Alasmidonta viridis - 1 fresh-dead, 2 relict
Elliptio dilatata - 3 fresh-dead, 2 relict
Lampsilis fasciola - 1 live, 4 fresh-dead, 1 relict
Lampsilis ovata - 1 fresh-dead
Leptodea fragilis - 1 fresh-dead
Medionidus conradicus - 3 fresh-dead, 6 relict
Obovaria subrotunda - 3 fresh-dead
Pegias fabula - 47 fresh-dead and relict
Pleurobema oviforme - 1 fresh-dead
Potamilus alatus - 2 fresh-dead
Ptychobranchus fasciolaris - 2 fresh-dead
Ptychobranchus subtentum - 1 live, 2 fresh-dead, 3 relict
Toxolasma lividus - 3 fresh-dead, 8 relict
Villosa iris - 2 live, 3 fresh-dead, 4 relict
Villosa taeniata - 5 fresh-dead, 8 relict
**Villosa trabalis* - 1 fresh-dead, 2 relict

Quantitative sampling: Ten square-meter quadrat samples taken produced no live mussels.

Little South Fork Cumberland River - at Freedom Church Ford, river mile 3.8, Wayne and McCreary Counties, Kentucky. November 14, 1985.

Elliptio dilatata - 1 fresh-dead
Lampsilis fasciola - 1 fresh-dead
Medionidus conradicus - 1 relict
Pegias fabula - 5 relicts
Ptychobranchus subtentum - 3 fresh-dead
Villosa iris - 2 fresh-dead
Villosa taeniata - 2 fresh-dead

Little South Fork Cumberland River - upstream from route 92 bridge crossing at river mile 14.2, Wayne and McCreary Counties, Kentucky. November 15, 1984.

Alasmidonta marginata - 1 relict
Lampsilis fasciola - 1 relict
Leptodea fragilis - 1 fresh-dead
**Pegias fabula* - 1 fresh-dead, 1 relict
Pleurobema oviforme - 1 relict
Potamilus alatus - 1 fresh-dead
Ptychobranchus subtentum - 1 relict
Toxolasma lividus - 1 fresh-dead
Villosa taeniata - 1 fresh-dead

Walkerana, 1995-1996, 8(19): 107-126

SUMMARY OF PRE-OPERATIONAL MONITORING OF THE MUSSEL FAUNA IN THE UPPER CHICKAMAUGA RESERVOIR (TENNESSEE RIVER) IN THE VICINITY OF TVA'S WATTS BAR NUCLEAR PLANT, 1983-1993

Steven Ahlstedt[1,2] and Thomas McDonough[1]

ABSTRACT – The populations of three freshwater mussel beds were sampled to provide information on the occurrence, relative abundance, distribution and condition of mussels in the upper Chickamauga Reservoir near Watts Bar Nuclear plant. Historically, 64 mussel species were documented in the study area before the river was substantially affected by human activities. The present fauna consists of only 30 species (13,455 specimens) including four federally listed species (*Dromus dromas, Cyprogenia stegaria, Lampsilis abrupta* and *Pleurobema plenum*). Shell-length measurement data for 6,067 specimens (30 species) shows that only larger size-classes of mussels remain. Thin-sectioning of mussel valves confirmed relatively old ages (33-49 years) for five common species. Eighty-four quadrat excavations (0.25 meter square) and sieving of river substrate produced evidence of recent reproduction for only one species (*Anodonta imbecillis*). Available evidence indicates that the mussel fauna in upper Chickamauga Reservoir is old, largely nonreproducing, and remnant from pre- and post-impoundment of the river.

Key words: Tennessee River, Unionidae, monitoring.

INTRODUCTION

Freshwater mussel populations at three mussel beds in upper Chickamauga Reservoir were sampled twice each year from 1983-1985 as part of pre-operational monitoring for Watts Bar Nuclear Plant (WBN) (TVA, 1986). This study provided baseline information on the occurrence, relative abundance, distribution and condition of mussels in this reach of the Tennessee River.

From 1986-1992, following delays in completion of WBN, pre-operational monitoring of the three mussel beds was reduced to biennial sampling to monitor changes or trends in mussel populations prior to operation of WBN (Ahlstedt, 1989, 1991). These efforts have re-vealed no statistically significant variation in the mussel communities of upper Chickamauga Reservoir. To supplement monitoring activities, two additional studies were conducted in 1993 to document the apparent lack of recruitment (reproduction) on all three mussel beds and determine the age structure

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of five mussel species common to these beds.

The pre-impoundment richness of the mussel fauna was documented by Ortmann (1918) who recognized 88 mussel species occurring in the Tennessee River upstream from Chattanooga. At least 64 species probably occurred near the Watts Bar Nuclear Plant site before the river was affected by substantial human impacts. Excavations of aboriginal shell mounds located along the banks of the river in this area attest to the extreme diversity and abundance of mussels that existed before impoundment of the river (Parmalee et *al.*, 1982). Quantitative data from excavated material indicate that the five most abundant species (*Dromus dromas, Elliptio dilatata, Actinonaias ligamentina, Elliptio crassidens* and *Pleurobema plenum*) comprised approximately 66% of the mussel community. With the exception of *E. crassidens,* these species are presently rare in the Tennessee River. Post-impoundment studies of the mussel fauna in upper Chickamauga Reservoir are largely limited to those conducted by Scruggs (1960), Isom (1969), Bates (1975), Pardue (1981) and TVA (1979) before 1978. Although sampling methods and area covered differed from present monitoring studies, it remains clear that the mussel fauna has declined by 50% from what was reported historically.

SITE DESCRIPTION

The reach of the Tennessee River included in this study meanders southwest from near Spring City towards Chattanooga, Tennessee. Two dams constructed and operated in this reach of the river by the Tennessee Valley Authority (TVA) for hydroelectric power, flood control and navigation have substantially altered the diverse and abundant freshwater mussel fauna reported historically from the river. Chickamauga Dam, located on the Tennessee River at mile 471, closed for filling in 1940 and impounds 58.9 miles of the river upstream to the base of Watts Bar Dam. Watts Bar Dam, located just upstream of our study reach at mile 529.9, closed in 1942.

The most upstream of the three mussel beds sampled (TRM 528-529L) is located on the opposite side of the river (left descending bank) and upstream from WBN (Fig. 1). The middle bed (TRMs 526-527R) is on the same side of the river as WBN (right descending bank), just downstream from the mouth of Yellow Creek and the WBN diffuser. The lowermost bed (TRMs 520-521L) is located six river miles downstream from WBN on the left descending side of the river. All three mussel beds were sampled near the overbank along the inside edge of the navigation channel. Substrates generally consisted of gravel, cobble, sand and relic shells of the Asian clam, *Corbicula fluminea.*

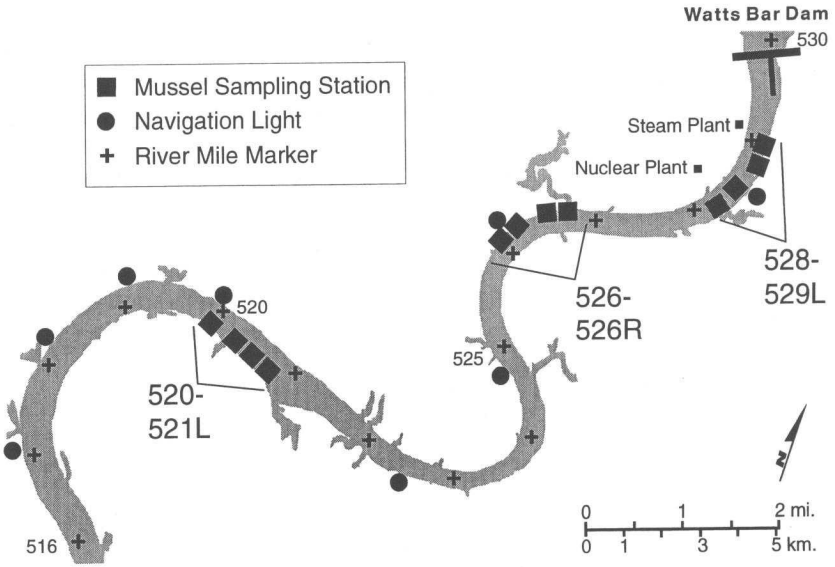

FIG. 1. Tennessee River downstream from Watts Bar Dam showing the locations of the three mussel sampling stations.

METHODS

Between 1983 and 1992, all live mussels were collected by four divers using scuba or surface-supplied air (hooka) during 11-minutes of bottom time at each sample location. Four sites were sampled in each of the three mussel beds for a total of 12 timed dives. Each sampling site was located using river mile markers, navigation buoys and bankside landmarks. Mussel specimens (excluding *Corbicula fluminea*) found were placed in mesh bags and brought to the dive boat at the end of each timed dive. All mussels were sorted, counted and identified to species. At each sampling site, up to 50 specimens of each species were measured (length, height and thickness) in millimeters using a dial caliper. All specimens were returned to the substrate in the collection vicinity. In 1993, at each sample location, a 0.25 square-meter quadrat sampler was used to determine the extent of recent successful mussel reproduction (Ahlstedt, 1991). The quadrat sampler was randomly placed on top of the substrate by divers and excavated by hand using a small garden shovel. All substrate within the sampling frame was removed to a depth of approximately 100-150 mm and placed in 5-gallon buckets. The buckets were attached to a cable and lifted by electric winch to a surface boat for processing.

Processing involved dumping the contents of the bucket into a series of three, stacked, rectangular box sieves (25, 13, 6 mm mesh sizes) mounted on a stand along the side of the boat. Contents were rinsed with river water using a battery operated pump. All size-classes of mussels were hand picked from the sieve screens. Live mussels were identified to species, counted and measured. A representative sample of the five most abundant species were collected for age determinations from each of the 12 sites. In previous studies, mussels have not been aged because of shell erosion and extremely close annulus formation near the ventral margin of the shell. Specimens were sacrificed and taken to TVA's Aquatic Biology Laboratory in Norris, Tennessee, for thin-sectioning of shell valves.

Thin-sectioning of valves involved the use of an Isomet low-speed saw and diamond wafering blade. Procedures used for thin-sectioning generally followed those used by Clark (1974), and Neves & Moyer (1988). The initial saw-blade cut was positioned anterior to the umbone so that it would pass cross-sectionally through the chondrophore, posterior to the ventral margin of the shell. The thickness of the valve cross-sections was 280 µm. Shell thin-sections were immersed in glycerine which helped to delineate or magnify growth lines. Specimens were then aged using 4X magnification.

RESULTS AND DISCUSSION

Twenty-two mussel species were reported during the 1990 mussel survey and only 16 species were found in 1992 (Table 1). This represents a loss of seven species of which six were reported as single specimens in 1990. One species was collected in 1992 that was not collected in 1990. All

TABLE 1. Total numbers and percent composition of mussel species at three sites (TRMs 520-521L, TRMs 526-527R, and TRMs 528-529L) in upper Chickamauga Reservoir in the vicinity of Watts Bar Nuclear Plant, 1990 and 1992.

Species	1990	(percent)	1992	(percent)
Actinonaias ligamentina	5		1	
Amblema plicata	10		13	
Anodonta grandis	20		5	
Anodonta imbecillis	1		0	
Anodonta suborbiculata	1		0	
Cyclonaias tuberculata	90	(9)	68	(10)
Ellipsaria lineolata	28		14	
Elliptio crassidens	524	(53)	424	(60)
Elliptio dilatata	1		0	
Lampsilis abrupta E	4		6	
Lampsilis ovata	1		0	
Leptodea fragilis	8		0	
Ligumia recta	2		3	
Megalonaias nervosa	3		4	
Obliquaria reflexa	11		6	
Plethobasus cyphyus	0		1	
Pleurobema cordatum	139	(14)	82	(12)
Pleurobema oviforme C	1		0	
Potamilus alatus	45		16	
Ptychobranchus fasciolaris	1		0	
Quadrula metanevra	8		8	
Quadrula pustulosa	79	(8)	48	(7)
Tritogonia verrucosa	9		9	
Total Specimens	991		708	
Total Species	22		16	

C - Cumberlandian Species
E - Endangered Species

TABLE 2. Relative abundance or presence of freshwater mussel species found in the vicinity of Watts Bar Nuclear Plant (generally Tennessee River Miles 470-529) during various surveys. Substantial variations exist in the methods employed, areas of coverage and amount of collection effort expended in these collections. Numbers in the table indicate the percentage composition of each species encountered in surveys which included quantitative results. Symbols: C–Cumberlandian Species; E–Endangered Species; T–Trace (less than 0.01 percent); X–Present but not counted.

Species	AD 1-1600	1850-1918	1956-1957	1965	1972-1974	1975-1977	1978	1983-1992
Actinonaias ligamentina	7.49	X	0.1	–	–	0.17	–	0.26
Actinonaias pectorosa C	–	X	–	–	–	–	–	–
Alasmidonta marginata	–	X	–	–	–	–	–	–
Amblema plicata	0.33	X	X	–	X	2.04	0.93	1.80
Anodonta grandis	–	–	–	X	–	–	0.21	0.87
Anodonta imbecillis	–	–	–	–	–	–	–	0.04
Anodonta suborbiculata	–	–	–	X	–	–	–	0.01
Cumberlandia monodonta	–	X	–	–	–	–	–	–
Cyclonaias tuberculata	3.19	X	2.0	12.71	–	10.22	6.84	5.95
Cyprogenia stegaria E	0.20	X	–	–	–	–	0.06	0.04
Dromus dromas CE	35.25	X	–	–	–	–	0.06	0.01
Ellipsaria lineolata	–	X	0.2	–	–	4.77	2.41	1.78
Elliptio crassidens	6.11	X	12.9	18.78	X	42.08	63.04	62.71
Elliptio dilatatus	11.36	X	1.1	6.08	–	0.34	0.21	0.13
Epioblasma arcaeformis C	1.37	X	–	–	–	–	–	–
Epioblasma capsaeformis C	0.27	X	–	–	–	–	–	–
Epioblasma flexuosa	0.09	–	–	–	–	–	–	–
Epioblasma florentina C	0.05	–	–	–	–	–	–	–
Epioblasma haysiana C	0.37	X	–	–	–	–	–	–
Epioblasma interrupta C	0.03	X	–	–	–	–	–	–
Epioblasma lenior C	–	X	–	–	–	–	–	–
Epioblasma lewisi	–	X	–	–	–	–	–	–
Epioblasma obliquata E	T	–	–	–	–	–	–	–
Epioblasma propinqua	2.70	X	–	–	–	–	–	–
Epioblasma stewardsoni C	0.44	X	–	–	–	–	–	–

TABLE 2. (cont.)

Species	AD 1-1600	1850-1918	1956-1957	1965	1972-1974	1975-1977	1978	1983-1992
Epioblasma torulosa/propinqua	0.11	–	–	–	–	–	–	–
Epioblasma triquetra	0.02	X	–	–	–	–	–	–
Epioblasma turgidula CE	0.06	–	–	–	–	–	–	–
Epioblasma/Villosa	0.12	–	–	–	–	–	–	–
Fusconaia barnesiana C	0.06	X	–	–	–	–	–	–
Fusconaia cor CE	–	X	–	–	–	–	–	–
Fusconaia cuneolus CE	–	X	–	–	–	–	–	–
Fusconaia ebena	–	–	0.1	–	–	–	–	–
Fusconaia subrotunda	4.97	X	–	–	–	–	–	0.01
Hemistena lata E	–	X	–	–	–	–	–	–
Lampsilis abrupta E	–	X	–	–	–	0.08	0.57	0.42
Lampsilis fasciola	0.01	X	–	–	–	–	–	–
Lampsilis ovata	0.20	X	X	–	–	–	0.09	0.19
Lasmigona complanata	–	–	–	X	–	–	–	0.01
Lasmigona costata	T	X	–	–	–	–	–	0.01
Lemiox rimosus CE	0.09	X	–	–	–	–	–	–
Leptodea fragilis	–	X	–	–	–	–	0.03	0.33
Leptodea leptodon	–	X	–	–	–	–	–	–
Lexingtonia dolabelloides C	0.63	X	–	–	–	–	–	–
Ligumia recta	0.03	X	X	–	–	0.51	0.42	0.48
Medionidus conradicus C	–	X	–	–	–	–	–	–
Megalonaias nervosa	–	–	–	–	–	–	0.15	0.23
Obliquaria reflexa	–	X	1.0	6.08	X	1.02	0.87	0.59
Obovaria olivaria	–	–	0.2	–	–	–	–	–
Obovaria retusa E	1.64	X	–	–	–	–	–	–
Obovaria subrotunda	0.64	X	–	–	–	–	–	–
Plethobasus cicatricosus E	0.73	–	–	–	–	–	–	–
Plethobasus cooperianus E	0.88	X	X	–	–	–	–	–

TABLE 2. (cont.)

Species	AD 1-1600	1850-1918	1956-1957	1965	1972-1974	1975-1977	1978	1983-1992
Plethobasus cyphyus	0.10	X	1.0	X	X	0.17	–	0.02
Pleurobema clava E	0.70	–	–	–	–	–	–	–
Pleurobema cordatum	4.88	X	74.6	31.49	X	14.99	12.50	14.34
Pleurobema oviforme C	–	X	–	–	–	–	0.09	0.06
Pleurobema plenum E	5.58	X	–	–	–	–	–	0.04
Pleurobema rubrum	2.20	X	–	–	–	–	0.03	0.03
Pleurobema spp.	2.26	–	–	–	–	–	–	–
Potamilus alatus	0.01	X	X	6.08	–	2.39	1.27	2.61
Ptychobranchus fasciolaris	0.91	X	0.01	–	–	–	–	0.01
Ptychobranchus subtentum C	0.06	X	–	–	–	–	–	–
Quadrula cylindrica	0.12	X	–	–	–	–	–	–
Quadrula intermedia CE	0.23	X	–	–	–	–	–	–
Quadrula metanevra	0.68	X	2.9	–	–	2.39	1.81	0.86
Quadrula pustulosa	0.34	X	2.2	18.78	X	17.55	8.10	5.42
Quadrula spp.	0.02	–	–	–	–	–	–	–
cf. *Strophitus undulatus*	T	X	–	–	–	–	–	–
Toxolasma lividus C	–	X	–	–	–	–	–	–
Tritogonia verrucosa	–	–	0.01	–	–	0.68	0.30	0.77
Truncilla donaciformis	–	–	0.01	–	–	–	–	–
Truncilla truncata	–	X	X	–	–	–	–	–
Villosa fabalis	–	X	–	–	–	–	–	–
Villosa nebulosa C	–	X	–	–	–	–	–	–
Villosa vanuxemensis C	0.06	X	–	–	–	–	–	–
Total Specimens	27,875	–	–	–	–	587	3,320	13,455
Species Listed	45	58	22	10	6	15	21	30
Combined Species	64			23				

seven species are now considered uncommon in upper Chickamauga Reservoir.

The total number of mussels found in 1992 (708 mussels) was 35% less than the numbers reported in 1990. The loss of mussel species and total numbers collected has continued to decline since sampling began in 1983 (TVA, 1986; Ahlstedt, 1989, 1991). Overall, relative abundance or presence of freshwater mussels has changed considerably in upper Chickamauga Reservoir, based upon pre- and post-impoundment studies (Table 2). Most of the declines in number of mussels reported since 1983 result from reduced abundance of four of the most common species (*Elliptio crassidens, Pleurobema cordatum, Cyclonaias tuberculata* and *Quadrula pustulosa*). Trend analysis of mussel abundance from 1983 to 1992 indicated few statistically significant differences because the losses have occurred gradually and trends are overridden by sampling error (Table 3).

Shell length measurement data indicate continued slow growth for seven of the 16 species since 1990. Remaining species had slightly lower mean lengths than reported in 1990 (Table 4). These results parallel those of

TABLE 3. Results of linear regression analyses testing for trends in number of mussels collected in Watts Bar Tailwater, 1983-92.

Species	Correlation coefficient		
	TRM 520	TRM 526	TRM 528
Actinonaias ligamentina	0.03	0.00	-0.03
Amblema plicata	0.08	-0.20	0.03
Anodonta grandis	0.05	0.09	-0.04
Cyclonaias tuberculata	0.31	-0.03	-0.15
Ellipsaria lineolata	-0.02	-0.08	0.08
Elliptio crassidens	-5.32*	-1.76	-1.39
Elliptio dilatata	-0.04	0.00	-0.01
Lampsilis abrupta	-0.02	0.02	0.08
Lampsilis ovata	-0.04*	0.00	-0.03
Leptodea fragilis	0.02	0.02	0.00
Ligumia recta	-0.03	-0.01	-0.03
Megalonaias nervosa	0.05	0.02	0.03
Obliquaria reflexa	0.02	-0.14	0.03
Pleurobema cordatum	-1.73*	-0.92	-0.57
Pleurobema oviforme	0.00	0.00	0.00
Pleurobema plenum	-0.04	0.00	-0.01
Potamilus alatus	0.12	0.11	0.09
Quadrula metanevra	-0.15*	0.01	0.04
Quadrula pustulosa	-0.33	-0.33	0.03
Tritogonia verrucosa	0.05	0.12	0.00
All mussels	-7.04**	-3.05	-1.87

* $P < 0.05$
** $P < 0.01$

other studies in the upper Chickamauga Reservoirm (Scruggs, 1960; TVA, 1975-1977; Bates, 1975; TVA, 1979; Pardue, 1981; TVA, 1983-1985, 1986, 1986-1992; Ahlstedt, 1989, 1991). Abundant species continued slow growth; however, mean shell length of some rarer species decreased slightly possibly due to low numbers sampled or overall poor condition (emaciated soft parts and shell erosion) which inhibits shell growth (Tables 5 and 6).

Shell measurement data from 1983-1992 included three species (An*odonta imbecillis, Obliquaria reflexa* and *Quadrula pustulosa*) which were represented by specimens in the 30 mm group (Table 7). All other mussel species were over 40 mm in length indicating lack of recruitment for several years.

Between 1956 and 1957, Scruggs (1960) studied commercial mussels stocks of the pigtoe, *Pleurobema cordatum,* in four Tennessee River

TABLE 4. Mean shell lengths (mm) of measured freshwater mussel species obtained during the 1990 and 1992 surveys from upper Chickamauga Reservoir near the Watts Bar Nuclear Plant site.

	1990		1992	
Species	Number	Mean	Number	Mean
Actinonaias ligamentina	5	110.38	1	94.80
Amblema plicata	10	102.16	13	105.46
Anodonta grandis	20	135.42	5	130.06
Anodonta imbecillis	1	52.00	–	–
Anodonta suborbiculata	1	126.20	–	–
Cyclonaias tuberculata	69	79.65	68	80.10
Ellipsaria lineolata	28	85.42	14	90.49
Elliptio crassidens	160	115.21	137	112.26
Elliptio dilatata	1	94.60	–	–
Lampsilis abrupta	4	105.95	6	108.85
Lampsilis ovata	1	121.70	–	–
Leptodea fragilis	8	110.46	–	–
Ligumia recta	2	172.60	3	157.27
Megalonaias nervosa	3	166.60	4	173.35
Obliquaria reflexa	11	55.06	6	57.17
Plethobasus cyphyus	–	–	1	91.40
Pleurobema cordatum	132	97.37	82	98.53
Pleurobema oviforme	1	72.80	–	–
Pleurobema rubrum	1	88.30	–	–
Potamilus alatus	45	142.78	16	142.99
Ptychobranchus fasciolaris	1	116.80	–	–
Quadrula metanevra	8	84.27	8	78.61
Quadrula pustulosa	78	57.56	48	56.37
Tritogonia verrucosa	9	107.59	9	106.24
Measured Specimens	598		421	
Average Mean Lengths		99.26		97.67
Species Total	22		16	

TABLE 5. Mean shell lengths (mm) of freshwater mussel species collected during various surveys from upper Chickamauga Reservoir near the Watts Bar Nuclear Plant Site.

Species	1957 (Scruggs, 1960)		1975-1977		1983-1985		1986-1992	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Actinonaias ligamentina	–	–	–	–	18	105.06	17	102.01
Amblema plicata	–	–	4	88.75	125	99.36	118	103.13
Anodonta grandis	–	–	–	–	47	122.67	70	128.46
Anodonta imbecillis	–	–	–	–	2	53.60	3	48.40
Anodonta suborbiculata	–	–	–	–	–	–	2	117.00
Cyclonaias tuberculata	–	–	37	71.70	413	77.87	355	78.32
Cyprogenia stegaria	–	–	–	–	5	55.02	–	–
Dromus dromas	–	–	–	–	1	60.10	–	–
Ellipsaria lineolata	–	–	19	73.42	137	85.00	102	86.11
Elliptio crassidens	–	–	212	96.59	912	109.25	752	117.00
Elliptio dilatata	–	–	2	105.50	10	100.51	7	103.66
Fusconaia subrotunda	–	–	–	–	2	61.40	–	–
Lampsilis abrupta	–	–	2	97.50	26	97.41	30	102.99
Lampsilis ovata	–	–	–	–	18	126.99	7	133.86
Lasmigona complanata	–	–	–	–	1	180.20	–	–
Lasmigona costata	–	–	–	–	–	–	1	122.10
Leptodea fragilis	–	–	–	–	15	100.39	29	101.83
Ligumia recta	–	–	–	–	34	159.66	30	152.97
Megalonaias nervosa	–	–	–	–	9	174.44	22	161.49
Obliquaria reflexa	–	–	4	44.25	43	54.28	36	55.39
Plethobasus cyphyus	–	–	1	72.00	2	91.80	1	91.40
Pleurobema cordatum	574	81.71	55	85.22	774	95.62	577	95.55
Pleurobema oviforme	–	–	–	–	3	70.83	5	71.00
Pleurobema plenum	–	–	–	–	5	65.40	–	–

TABLE 5. (cont.)

Species	1957 (Scruggs, 1960)		1975-1977		1983-1985		1986-1992	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Pleurobema rubrum	–	–	–	–	3	87.97	1	88.30
Potamilus alatus	–	–	6	128.00	167	139.48	183	141.63
Ptychobranchus fasciolaris	–	–	–	–	1	94.40	1	116.80
Quadrula metanevra	–	–	10	71.10	78	77.47	38	79.38
Quadrula pustulosa	–	–	70	50.94	450	56.64	275	57.00
Tritogonia verrucosa	–	–	1	117.00	47	116.04	57	110.00
Measured Specimens	574		423		3348		2719	
Total Species	1		13		28		25	

TABLE 6. Results of linear regression analyses testing for trends in lengths of mussels collected in Watts Bar Tailwater, 1983-92.

Species	Correlation coefficient		
	TRM 520	TRM 526	TRM 528
Actinonaias ligamentina	-1.22	1.22	1.94
Amblema plicata	2.41*	0.69	-0.35
Anodonta grandis	8.71	1.43*	3.14*
Cyclonaias tuberculata	0.38**	0.18	0.16
Ellipsaria lineolata	0.48	0.28	0.27
Elliptio crassidens	0.50***	0.42**	0.89***
Elliptio dilatata	-0.91		0.57
Lampsilis abrupta	5.97	0.28	2.27**
Lampsilis ovata	-1.58	0.00	-0.34
Leptodea fragilis	0.00	0.04	2.60
Ligumia recta	0.56	1.89	1.22
Megalonaias nervosa	5.00*	0.17	2.60
Obliquaria reflexa	0.78	0.35	1.13***
Pleurobema cordatum	-0.02	0.80***	0.23
Pleurobema oviforme			0.53
Pleurobema plenum	-4.00		0.00
Potamilus alatus	1.67*	0.07	0.56
Quadrula metanevra	0.93	-0.14	-0.33
Quadrula pustulosa	0.05	0.17	0.14
Tritogonia verrucosa	3.36	-1.31	3.44

* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

impoundments. He concluded that *P. cordatum* had ceased reproduction in the Tennessee River as only larger adults were present. Based upon his measurement data of pigtoes from upper Chickamauga Reservoir, average mean lengths of 574 specimens was 81.71 mm. Studies by TVA from 1975-1977 and 1983-1993 report greater mean lengths of pigtoes at 85.22 mm (55 specimens) and 95.60 mm (1351 specimens), respectively. Our findings support Scruggs' conclusions that successful pigtoe reproduction has not occurred since the mid-1950's.

Shell length measurement data for practically all mussel species examined in upper Chickamauga Reservoir indicate only remnant populations of larger individuals from pre-and immediate post-impoundment of the river. In order to determine if successful reproduction has recently occurred, 84 quadrat excavations were made throughout the three mussel beds. Of the 63 mussel specimens found during quadrat excavations, all were large adults with only one small (30 mm) *Anodonta imbecillis* found (Table 7).

Historically, the only age-class information existing for mussels from upper Chickamauga is reported by Scruggs (1960). In 1957, Scruggs aged

TABLE 7. Freshwater mussel frequency of occurrence by shell lengths from 1983-1985 and 1986-1993 surveys of the Tennessee River miles 520-521L, 526-527R, and 528-529L.

		Shell length in 10 millimeter intervals																Mean	
	Period	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	length	Totals
Actinonaias ligamentina	1983-85							5	8	5									105.06	18
	1986-93						1	10	1	3	2								102.02	17
Amblema plicata	1983-85					8	16	43	32	21	2	3							99.36	125
	1986-93				2	3	11	29	32	33	6	2							103.13	118
Anodonta grandis	1983-85						1		8	9	15	10	3	1					122.67	47
	1986-93						3		7	10	18	14	12	6					128.46	70
Anodonta imbecillis	1983-85			2															53.60	2
	1986-93	1		2															48.40	3
Anodonta suborbiculata	1986-93								1		1								117.00	2
Cyclonaias tuberculata	1983-85			2	52	194	140	25											77.87	413
	1986-93			2	47	151	137	17		1									78.32	355
Cyprogenia stegaria	1983-85			4	1														55.02	5
Dromus dromas	1983-85				1														60.10	1
Ellipsaria lineolata	1983-85			4	15	18	40	52	8										85.00	137
	1986-93			2	9	17	30	37	4	3									86.11	102
Elliptio crassidens	1983-85						7	117	356	333	90	9							109.25	912
	1986-93						3	71	222	337	101	14	3	1					111.74	752
Elliptio dilatata	1983-85							4	5	1									100.51	10
	1986-93							3	2	2									103.66	7
Fusconaia subrotunda	1983-85			1	1														61.40	2

TABLE 7. (cont.)

		Shell length in 10 millimeter intervals																Mean	
	Period	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	length	Totals
Lampsilis abrupta	1983-85					2	4	8	10	2									97.41	26
	1986-93						2	11	9	7	1								102.99	30
Lampsilis ovata	1983-85								1	3	6	6	2						126.99	18
	1986-93									1	1	3	1	1					133.86	7
Lasmigona complanata	1983-85																1		180.20	1
Lasmigona costata	1986-93										1								122.10	1
Leptodea fragilis	1983-85			1			4	1	3	6									100.39	15
	1986-93					4	4	2	9	5	4	1							101.83	29
Ligumia recta	1983-85												8	8	10	6	2		159.66	34
	1986-93								1		1	4	7	4	7	6			152.97	30
Megalonaias nervosa	1983-85														2	4	2	1	174.44	9
	1986-93										1		4	5	3	7	2		161.49	22
Obliquaria reflexa	1983-85	1	10	24	8														54.28	43
	1986-93		7	21	8														55.35	36
Plethobasus cyphyus	1983-85						1	1											91.80	2
	1986-93							1											91.40	1
Pleurobema cordatum	1983-85				2	29	159	352	192	32	2	2	1	1	2				95.62	774
	1986-93			1	4	24	119	233	157	37	2								95.55	577
Pleurobema oviforme	1983-85				1	2													70.83	3
	1986-93				2	3													71.00	5
Pleurobema plenum	1983-85			2	2		1												65.40	5

TABLE 7. (cont.)

		Shell length in 10 millimeter intervals																Mean	
	Period	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	length	Totals
Pleurobema rubrum	1983-85						1	2											87.97	3
	1986-93						1												88.30	1
Potamilus alatus	1983-85		1					4	6	12	18	37	35	26	22	4	2		139.48	167
	1986-93					1	1	1	3	12	15	40	47	46	15	1	1		141.63	183
Ptychobranchus fasciolaris	1983-85							1											94.40	1
	1986-93									1									116.80	1
Quadrula metanevra	1983-85		1	1	10	36	25	5											77.47	78
	1986-93			1	7	9	15	5	1										79.38	38
Quadrula pustulosa	1983-85		50	256	138	5	1												56.64	450
	1986-93	2	30	151	85	5	2												57.00	275
Tritogonia verrucosa	1983-85					1	1	8	8	7	13	6	3						116.04	47
	1986-93					3	2	12	14	9	9	6	2						110.00	57

TABLE 8. Age and shell length measurement data for five common mussel species in upper Chickamauga Reservoir near the Watts Bar Nuclear Plant site.

	P. cordatum TVA (1993)	*C. tuberculata* TVA (1993)	*Q. pustulosa* (TVA (1993)
Number measured	33	27	17
Length range (mm)	88. 7-110.5	55.3-92.4	52.2-70.8
Mean length (mm)	98.5	80.1	59.9
Number aged	32	23	17
Age range	28-64	26-50	23-44
Mean age	49	34	33

	E. lineolata TVA (1993)	*E. crassidens* TVA (1993)
Number measured	7	28
Length range (mm)	57.5-97.0	97.2-122.1
Mean length (mm)	87.3	112.1
Number aged	7	28
Age range	27-51	30-46
Mean age	34	36

	P. cordatum (Scruggs) 1957	*P. cordatum* TVA (1983-1992)	*P. cordatum* (TVA 1993)
Number measured	574	1351	33
Length range (mm)	40-119	–	88.7-110.5
Mean length (mm)	81.71	95.6	98.5
Number aged	212	–	32
Range	6-32	–	28-64
Mean age	22	–	49

212 specimens of *Pleurobema cordatum* by counting external growth rests on the shell and reported that the average age was 22 years. Based upon thin-sectioning of valves, the average age for 32 pigtoe specimens collected in 1993 was 49 years. Age determinations in 1993 for four other species revealed mean ages for *Cyclonaias tuberculata* (34 years), *Quadrula pustulosa* (33 years), *Ellipsaria lineolata* (34 years) and E*lliptio crassidens* (36 years) (Table 8). Scruggs findings that the pigtoe population was old and non-reproducing in 1957 further supports recent findings that the pigtoe population is now considerably older and other mussel species are suffering a similar fate.

Fourteen federally listed endangered species are documented from upper Chickamauga Reservoir prior to extensive modifications of the river (Table 2). Since sampling was begun in 1983, only four species (*Cyprogenia stegaria, Dromus dromas, Lampsilis abrupta* and *Pleurobema plenum*) have been found and exist as relict populations. Two of the four species (*D. dromas* and *P. plenum*) were once considered the most abundant

TABLE 9. Freshwater mussel species reported from the Tennessee River (A = Archaeological).

		Pre-(1960)	Pre-(1970)	Pre-(1980)	Pre-(1990)	(1993)	Status
Actinonaias ligamentina	A	X	X	–	X	X	relict
Actinonaias pectorosa	A	X	–	–	–	–	extirpated
Alasmidonta marginata	A	–	–	–	–	–	extirpated
Alasmidonta viridis	A	–	–	–	–	–	extirpated
Amblema plicata	A	X	X	X	X	X	reproducing
Anodonta grandis	A	X	X	X	X	X	reproducing
Anodonta imbecillis	–	X	X	X	X	X	reproducing
Anodonta suborbiculata	–	–	X	X	X	X	reproducing
Arcidens confragosus	–	–	X	X	X	X	reproducing
Cumberlandia monodonta	–	X	X	X	X	X	relict
Cyclonaias tuberculata	A	X	X	X	X	X	reproducing
*Cyprogenia stegaria**	A	X	X	X	X	X	relict
*Dromus dromas**	A	X	X	X	X	–	extirpated
Ellipsaria lineolata	A	X	X	X	X	X	reproducing
Elliptio crassidens	A	X	X	X	X	X	reproducing
Elliptio dilatata	A	X	X	X	X	X	relict
Epioblasma arcaeformis	A	–	–	–	–	–	extinct
Epioblasma biemarginata	A	X	–	–	–	–	extinct
Epioblasma brevidens	A	–	–	–	–	–	extirpated
Epioblasma capsaeformis	A	X	–	–	–	–	extirpated
Epioblasma flexuosa	A	X	–	–	–	–	extinct
*Epioblasma f. florentina**	A	–	–	–	–	–	extinct
*Epioblasma haysiana**	A	X	–	–	–	–	extinct
*Epioblasma o. obliquata**	A	X	–	–	–	–	extirpated
Epioblasma personata	A	–	–	–	–	–	extinct
Epioblasma propinqua	A	X	–	–	–	–	extinct
Epioblasma stewardsoni	A	X	–	–	–	–	extinct
*Epioblasma t. torulosa**	A	X	–	–	–	–	extinct
Epioblasma triquetra	A	X	–	–	–	–	extirpated
*Epioblasma turgidula**	A	–	–	–	–	–	extinct
Fusconaia barnesiana	A	X	–	–	–	–	extirpated
*Fusconaia cor**	A	X	–	–	–	–	extirpated
*Fusconaia cuneolus**	A	X	–	–	–	–	extirpated
Fusconaia ebena	–	X	X	X	X	X	reproducing
Fusconaia flava	–	–	–	X	X	X	reproducing
Fusconaia subrotunda	A	X	X	X	X	X	reproducing
*Hemistena lata**	–	X	–	X	–	–	relict
*Lampsilis abrupta**	–	X	X	X	X	X	relict
Lampsilis fasciola	A	X	–	–	–	–	extirpated
Lampsilis ovata	A	X	X	X	X	X	relict
Lampsilis teres	–	X	X	X	X	X	relict
*Lampsilis virescens**	A	–	–	–	–	–	extirpated
Lasmigona complanata	–	–	X	X	X	X	reproducing
Lasmigona costata	A	X	–	–	X	–	extirpated
Lasmigona holstonia	–	X	–	–	–	–	extirpated
*Lemiox rimosus**	A	X	–	–	–	–	extirpated
Leptodea fragilis	A	X	X	X	X	X	reproducing

TABLE 9. (cont.)

		Pre-(1960)	Pre-(1970)	Pre-(1980)	Pre-(1990)	(1993)	Status
Leptodea leptodon	–	X	–	–	–	–	extirpated
Lexingtonia dolabelloides	A	X	X	X	X	–	extirpated
Ligumia recta	A	X	X	X	X	X	relict
Medionidus conradicus	–	X	–	–	–	–	extirpated
Megalonaias nervosa	–	X	X	X	X	X	reproducing
Obliquaria reflexa	A	X	X	X	X	X	reproducing
Obovaria olivaria	–	X	X	X	–	–	extirpated
*Obovaria retusa**	A	X	X	X	X	–	relict
Obovaria subrotunda	A	X	–	X	–	–	relict
*Pegias fabula**	A	X	–	–	–	–	extirpated
Plectomerus dombeyanus	–	–	–	–	X	X	reproducing
*Plethobasus cicatricosus**	A	–	X	X	X	–	relict
*Plethobasus cooperianus**	A	X	X	X	X	X	relict
Plethobasus cyphyus	A	X	X	X	X	X	relict
*Pleurobema clava**	A	X	–	–	–	–	extirpated
Pleurobema coccineum	–	X	–	X	X	X	reproducing
Pleurobema cordatum	A	X	X	X	X	X	relict
Pleurobema oviforme	A	–	X	X	X	–	relict
*Pleurobema plenum**	A	X	–	X	X	–	relict
Pleurobema pyramidatum	A	X	X	X	X	–	relict
Potamilus alatus	A	X	X	X	X	X	reproducing
Potamilus ohiensis	–	–	X	X	X	–	reproducing
Ptychobranchus fasciolaris	A	X	X	X	X	–	relict
Ptychobranchus subtentum	A	X	–	–	–	–	extirpated
Quadrula apiculata	–	–	–	–	X	X	reproducing
Quadrula cylindrica	A	–	–	–	X	–	relict
*Quadrula fragosus**	–	X	–	–	–	–	extirpated
*Quadrula intermedia**	A	X	–	–	–	–	extirpated
Quadrula metanevra	A	X	X	X	X	X	reproducing
Quadrula nodulata	–	–	–	–	X	X	reproducing
Quadrula pustulosa	A	X	X	X	X	X	reproducing
Quadrula quadrula	–	X	X	X	X	X	reproducing
*Quadrula sparsa**	A	–	–	–	–	–	extirpated
Strophitus undulatus	A	X	–	–	–	–	extirpated
Toxolasma lividus	A	–	–	X	X	X	relict
Toxolasma parvus	–	–	X	X	X	X	reproducing
Tritogonia verrucosa	–	X	X	X	X	X	reproducing
Truncilla donaciformis	–	X	X	X	X	X	reproducing
Truncilla truncata	–	X	X	–	X	X	reproducing
Villosa fabalis	A	–	–	–	–	–	extirpated
Villosa iris	A	X	–	–	–	–	extirpated
Villosa taeniata	A	X	–	–	–	–	extirpated
*Villosa trabalis**	–	X	–	–	–	–	extirpated
Villosa vanuxemensis	A	–	–	–	X	–	extirpated
Total number of species	64	67	42	46	51	39	

*Federally listed endangered species are marked with an asterisk.
Total number of mussel species reported from Tennessee River (91); federally listed endangered (23); extinct (10); extirpated (32); relict (21); reproducing (28).

of five species which comprised 66% of all shell material excavated from aboriginal shell mounds in the reservoir (Parmalee *et al.*, 1982). These findings are not unique to upper Chickamauga Reservoir. Of the 91 mussel species reported historically in the river, only 28 species are considered reproducing. Reproduction is largely limited to mussel species and their fish host(s) which have adapted to impoundment conditions, especially in the lower 350 miles of the river downstream from Guntersville Dam. At least 19 of the 28 reproducing species are taken commercially for the cultured pearl industry. Other mussel species documented from the river have been reduced to relict status because of their scarcity and apparent lack of reproduction. Still others have been extirpated from the mainstem river fauna, or are extinct (Table 9).

SUMMARY AND CONCLUSIONS

Mussel populations in upper Chickamauga Reservoir have suffered serious declines from a high of 64 species reported historically near the Watts Bar Nuclear Plant to approximately 30 species present today. Total number of mussels found since sampling began in 1983 have continued to decline between sampling years. Few of these are statistically significant because the losses have occurred gradually and trends are overridden by sampling error.

Shell length measurement data show continued slow growth for the more abundant species; however, rarer species decreased in mean lengths, possibly due to the low numbers of mussels sampled or overall poor condition (emaciated soft parts and shell erosion). Only three species were reported in the 30 mm size grouping. All other mussel species measured since sampling began in 1983 were over 40 mm in length. Quadrat excavations support our findings that little or no recruitment to the fauna has taken place for several years.

Age-class determinations for five of the most common mussel species adds further support that mussel populations are old and are remnants from pre-and post-impoundment periods. Conditions which caused the demise of the mussel fauna in upper Chickamauga Reservoir and elsewhere on the Tennessee River are poorly understood. Likely factors include loss of fish host, substrate scouring, sediment toxicity, thermal and dissolved oxygen problems, and settling of detrital material in upstream reservoirs. Mussel populations near the Watts Bar Nuclear Plant will continue to age, add shell growth for some species, and gradually dieoff over time.

ACKNOWLEDGEMENTS

We wish to express our gratitude and appreciation to our former colleagues at the Tennessee Valley Authority who helped us with this project. Special thanks are given Neil Woomer who was project supervisor and diver. We also appreciate Gary Hickman, Charlie Saylor, Bennie Kerley, Wayne Wilson, Dennis Baxter and Johnny Buchanan for providing numerous hours of help diving on this project.

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