

Shin C. P. and Allmon W. D. (2025) Evaluating morphological species recognition in fossil and modern gastropods (Littorinidae, periwinkles). *Paleobiology*. Supplementary Materials.

Supplementary Table 1. Identifying features in the studied *Littorina* species focused particularly on those differentiating *L. plena* and *L. scutulata*, based on the major taxonomic compilation (Reid 1996) and other references (noted below). Features described for *L. plena* or *L. scutulata* are often in comparison with each other; there are no consistent conchological features that differentiates the two species.

	† <i>L. petricola</i>	<i>L. keenae</i>	<i>L. plena</i>	<i>L. scutulata</i>
Shell				
Size	Up to 21mm. Average 12mm (this study)	Up to 22mm. Average 6 to 12mm (California, USA, Elahi et al. 2020)	Up to ~19mm. Average 6mm (Washington, USA, Hohenlohe and Boulding 2001) to 9mm (Oregon and California, USA, Murray 1982), generally smaller than <i>L. scutulata</i> (Chow 1987, Rugh 1997)	Up to 18mm. Average 8mm (Hohenlohe and Boulding 2001) to 12mm (California, USA, Murray 1982)
Shape	Turbinate	Turbinate		Conical
Sculpture	Fine ribs	Typically eroded; flattened parietal area	Commonly with basal ridge (Rugh 1997, 62% of individuals in Hohenlohe and Boulding 2001)	Weaker sculpture. Rarely with basal ridge (16% of specimens in Hohenlohe and Boulding 2001)
Striping	Unknown	Occasional banding, usually with cream basal band	Commonly with pale basal band (Murray 1982, Chow 1987, Rugh 1997) sometimes also with three light bands (Pacific Northwest, Rugh 1997)	Occasionally spotted or banded (Murray 1982, Chow 1987, Hohenlohe and Boulding 2001), sometimes two light bands (Pacific Northwest, Rugh 1997)

	† <i>L. petricola</i>	<i>L. keenae</i>	<i>L. plena</i>	<i>L. scutulata</i>
Tessellation	Unknown	Varying intensity and pattern size	Usually with fine pattern (Chow 1987, Hohenlohe and Boulding 2001)	Commonly with coarse pattern (Chow 1987, Hohenlohe and Boulding 2001)
<i>Anatomy</i>				
Cephalic tentacle coloration	Not applicable	Black	Broad unbroken black central stripe (96% of specimens, Hohenlohe and Boulding 2001)	Transverse bands (90% in Hohenlohe and Boulding 2001)
Pelagic egg capsules	Not applicable	Biconvex capsules with a single rim	Biconvex capsules with rims of equal diameter (Murray 1979) or one rim, slightly larger capsule than <i>L. scutulata</i> (Hohenlohe 2002)	Biconvex capsules with rims of unequal diameter (Murray 1979, Strathmann 1987) or one rim (Hohenlohe 2002)
Number of eggs	Not applicable	Usually one egg per capsule (Murray 1979)	Smaller and generally more eggs per capsule for <i>L. plena</i> than <i>L. scutulata</i> (Murray 1979, Strathmann 1987, Hohenlohe 2002)	
Pallial oviduct	Not applicable	Single albumen gland loop	Shorter copulatory bursar with septate, long straight section	Long copulatory bursa and short straight section
Penis morphology	Not applicable	Usually with two mamilliform glands	Longer than <i>L. scutulata</i> with long basal filament	Smaller than <i>L. plena</i> with terminal filament

	† <i>L. petricola</i>	<i>L. keenae</i>	<i>L. plena</i>	<i>L. scutulata</i>
<i>Ecology</i>				
Distribution	Oregon and California, USA	California, USA and Baja California, Mexico	Gulf of Alaska to California, USA	Southeast Alaska, USA to Baja California, Mexico
Habitat	Sheltered environments	Exposed high shore (Behrens Yamada 1992)	Occupies similar vertical and local habitats as <i>L. scutulata</i> (Behrens Yamada 1992, Hohenlohe 2003b) although perhaps more associated with habitats that have freshwater input (Hohenlohe 2003a); more often in sheltered conditions (Rugh 1997)	More commonly on exposed coasts (Rugh 1997)
Development	Unknown	Planktotrophic	Planktotrophic	
<i>Molecular</i>				
Genetic difference	Not applicable	Distinct; confirmed as basal member of genus (Reid et al. 2012)	Greater genetic differentiation between populations of the two species than within species (average 0.707 Nei's genetic similarity, enzyme data, Mastro 1982); 0.276 to 0.477 Nei's genetic distance between the two species (allozymes, Reid et al. 1996)	
Alleles	Not applicable	Not used to differentiate this species from others	Statistically significant allelic differences (Mastro 1982)	
Molecular identification	Not applicable	Not used to differentiate this species from others	“Two widely spaced bands” with mitochondrial cytochrome b fragments (Hohenlohe and Boulding 2001)	“Three closely spaced bands” with mitochondrial cytochrome b fragments (Hohenlohe and Boulding 2001)

Supplementary Table 2. List of samples included in this study sorted by species, age, and region.

Age	Region	Catalog number	Location	Specimens
† <i>Littorina petricola</i> Arnold, 1908				
Pliocene, Etchegoin Formation	California	PRI 76551	Kettleman Hills location 219, North Dome	10
		PRI 76603	Kettleman Hills location 219, North Dome	1
		PRI 71514	Kettleman Hills location 249	5
		PRI 71820	Kettleman Hills Well 34-1-P	5
<i>Littorina keenae</i> Rosewater, 1978				
Late Pleistocene, Quaternary terrace	California	LACMIP 5100.71	Point Vincente, Palos Verdes Estates	29
		LACMIP 7220.106	Point Loma, San Diego	30
		LACMIP 23605.80	Sunset Cliffs, San Diego	30
Late Pleistocene, Quaternary terrace	Baja California	LACMIP 10131.29	Punta Banda, Bahia el Playon	29
Late Pleistocene, unspecified		LACMIP 8221.73	Baja California	30
Recent	California	NHM	Garrapata Creek, Carmel	30
		LACM 66066	Shell Beach, San Luis Obispo	30
		LACM 60122	Point Fermin, Palos Verdes Peninsula	30
		LACM 113261	Santa Catalina Island, California Channel Islands	30
		LACM 1965-29.25	Point Loma, San Diego	30
	Baja California	NHM	University Campus, Ensenada	30
		LACM 1973-2.20	Caleta Hassler, Isla de San Martin	30
		LACM 1949-154.21	Caleta Melpomene, Isla Guadalupe	30

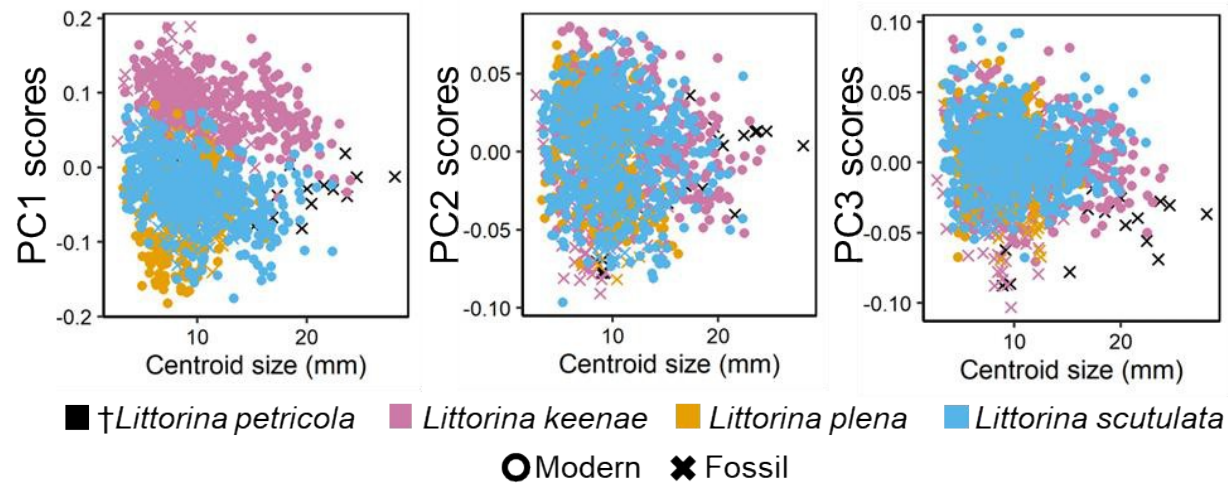
Age	Region	Catalog number	Location	Specimens
		LACM 1971-162.33	Punta Rompiente	30
		USNM 265807	Punta Abreojos	30
		USNM 47089	Todos Santos Bay	30
<i>Littorina plena</i> Gould, 1849				
Late Pleistocene, Quaternary terrace	California	LACMIP 23605.405	Sunset Cliffs, San Diego	30
		LACMIP 7220.166	Point Loma, San Diego	30
Late Pleistocene, unspecified	Baja California	LACMIP 10131.30	Punta Banda	30
Recent	Alaska	USNM 47067	(Label identifies as <i>L. scutulata</i> ) Kodiak	27
		NHM	Outside Beach, Seldovia	26
		USNM 221250	(Label identifies as <i>L. scutulata</i> ) Station 1135, Port Etches	30
	British Columbia	NHM	Station 5, Victoria	13
	Washington	NHM	Cape Flattery	17
	Oregon	LACM 35359	Nehalem River	30
	California	LACM 1949-2.5	Albion River	30
		LACM 1948-39.5	Oyster Cove, Tomales Bay	30
		LACM 60123	Point Fermin, Palos Verdes Peninsula	30
<i>Littorina scutulata</i> Gould, 1849				
Pleistocene, unspecified	Baja California	PRI 72695	Punta China	9
Middle Pleistocene, Quaternary terrace	California	LACMIP 6153.2	Rancho Palos Verdes	30
Late Pleistocene, Quaternary terrace		LACMIP 13031.70	Palos Verdes	30
		LACMIP 5100.80	Point Vincente, Palos Verdes Estates	30

Age	Region	Catalog number	Location	Specimens
Recent	Alaska	LACMIP 10167.130	Point Loma, San Diego	30
		USNM 221248	Sitka Harbor, Alaska	20
	British Columbia	LACM 1973- 40.15	Departure Bay, Vancouver Island	30
		LACM 1968-73.3	Amphitrite Point, Vancouver Island	30
	Washington	NHM	Station 5, Victoria	30
		LACM 1977-49.9	Shi Shi Beach	30
		LACM 60096	Vashon Island	30
		AMNH	Depoe Bay	30
		AMNH	(Label identifies as <i>L. keenae</i> ) Cape Arago State Park, Coos Bay	17
	California	LACM 1970- 70.25	Shelter Cove, Humboldt	30
		LACM 1948- 37.11	Nick's Cove, Tomales Bay	30
		NHM	Garrapata Creek, Carmel	30
	Baja California	LACM 60071	San Pedro	30
		LACM 64118	Palos Verdes Peninsula	30
		LACM 1964- 32.27	Ensenada	30
		LACM 1971- 162.32	Punta Rompiente	30
		USNM 207285	Socorro Island	30

Supplementary Table 3. GenBank numbers of *Littorina* sequences used (selected from Reid et al. 2012).

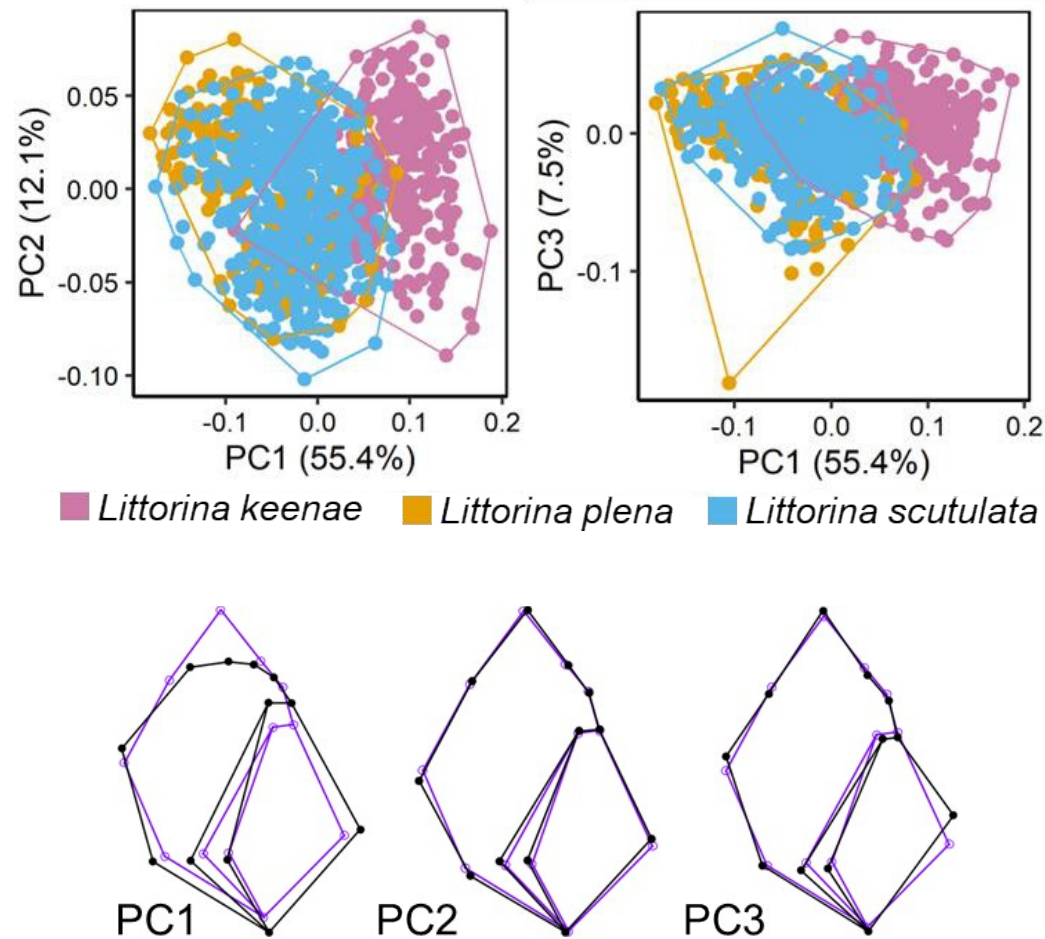
Species	Sample locality	28S rRNA	12S rRNA	COI
<i>Littorina keenae</i> Rosewater, 1978	Baker's Beach, San Francisco, California, USA	AJ488671	AJ488753	AJ488629
<i>Littorina plena</i> Gould, 1849	Baker's Beach, San Francisco, California, USA	AJ488673	AJ488755	AJ622948
<i>Littorina scutulata</i> Gould, 1849	Big Sur, California, USA	HE590812	HE590784	HE590841

Supplementary Fig. 1. *Littorina* centroid sizes plotted against principal component analyses using all specimens (from Figure 6). Note that the x axes remain the same among graphs.





Supplementary Fig. 2. Principal component analysis of landmark data for modern *Littorina* specimens only, with polygons to outline each species. Shape changes along each principal component are illustrated by wireframe diagrams (from purple, minimum principal component values, to black outlines, maximum principal component values).



Supplementary Fig. 3. Principal component analysis of landmark data for fossil data only of the four *Littorina* species, with polygons to delineate the bounds of each species' specimens. Shape change along each axis is shown by wireframe diagrams (from purple, minimum principal axis values, to black outlines, maximum principal axis values).

