

RESEARCH NOTE

Crepidula convexa Say, 1822 (Caenogastropoda: Calyptraeidae) in Washington State, U.S.A.

Rachel Collin¹, Marjorie J. Wonham^{2*}, and Kelly R. Barr³

¹ Smithsonian Tropical Research Institute, Apartado Postal 0843-03092, Balboa, Ancon, República de Panamá, collinr@naos.si.edu

² Department of Zoology, University of Washington, Box 351800, 24 Kincaid Hall, Seattle, Washington 98195-1800, U.S.A.

³ Department of Biology, University of Louisiana, P.O. Box 42451, Lafayette, Louisiana 70504, U.S.A.

Abstract: With the increasing attention to the expansion and impact of invasive species, it has become more important to document carefully new observations of introduced species. Here we document the occurrence of *Crepidula convexa*, a species from the north Atlantic, in Washington State, U.S.A. DNA sequence data suggest that the animals in Washington originated from the northern part of the species's native range.

Keywords: Gastropod taxonomy, cryptic species, introductions

Several species of calyptraeid gastropods (slipper limpets, cup-and-saucer limpets, and hat limpets) have successfully invaded new locales following human-mediated introductions. Two are now particularly widespread. *Crepidula fornicata* (Linnaeus, 1758), native to the northwest Atlantic, has invaded much of the northern coast of Europe since its introduction to England on oysters at the turn of the century (Blanchard 1997, Minchin *et al.* 1995). Its range now also extends into the Mediterranean (Zibrowius 1992). *Crepidula fornicata* was also introduced with shipments of the Atlantic oyster *Crassostrea virginica* (Gmelin, 1791) to Puget Sound and Willapa Bay in Washington State and Humboldt Bay, California, on the Pacific coast of North America (Carlton 1979, 1992, Wonham and Carlton 2005). *Crepidula onyx* Sowerby, 1824, a similar species native to southern California, has become widespread in Asia (Korea: Choe and Park 1992, Japan: Ekawa 1985, Hong Kong: Morton 1987) since it was first reported in Japan in 1968 (Woodruff *et al.* 1986).

Other introduced calyptraeids have more limited non-native ranges. *Crepidula convexa* Say, 1822 is native to the Atlantic coast of North America from Nova Scotia to Georgia (Collin 2002). It was introduced to the Pacific coast in San Francisco Bay, California with shipments of Atlantic oysters (Carlton 1979, 1992, Wonham and Carlton 2005). The Atlantic species *Crepidula plana* Say, 1822 is similarly thought to have been introduced to Puget Sound, Willapa Bay, and San Francisco Bay (Carlton 1979, 1992, Wonham

and Carlton 2005). *Bostrycapulus calyptraeformis* (Deshayes, 1830) has been introduced into Hawai'i, where it was reported as *Crepidula aculeata* (Gmelin, 1791) and an undetermined species of *Bostrycapulus* (also usually cited as *C. aculeata*) (Collin 2005) has recently become established in Alicante Harbor, Spain (Zibrowius 1992).

The apparent contained distributions of these species may reflect a truly limited establishment in the new region, or they may be artifacts of limited collection records or misidentifications as other species. Here we report an additional location in the North Pacific in which *Crepidula convexa* has become established. Given the complicated taxonomic history of calyptraeid gastropods and the large number of morphologically cryptic species, genetic analysis is particularly useful in confirming shell-based identifications and determining source populations for introduced species. We use morphological and genetic analysis to confirm the presence and source of *C. convexa* in Padilla Bay, northern Puget Sound, Washington, USA, and discuss the implications of these new records.

Animals of the genus *Crepidula* are found on the intertidal mudflats of Padilla Bay (48°28'N, 122°31'W; Fig. 1) almost exclusively as epibionts on the introduced Asian mudsnail *Batillaria cumingi* (Crosse, 1862) (previously referred to as *Batillaria attramentaria* [Sowerby, 1855] on the Pacific coast of North America) (O'Connor *et al.* 2002). Individuals were collected from *B. attramentaria* in March 2001 and preserved in 70% ethanol. Examination of their shell morphology and anatomy showed them to be morphologically indistinguishable from *Crepidula convexa*. The dark

Current address: University of Alberta CAB 632, Edmonton, Alberta, Canada T6G 2G1

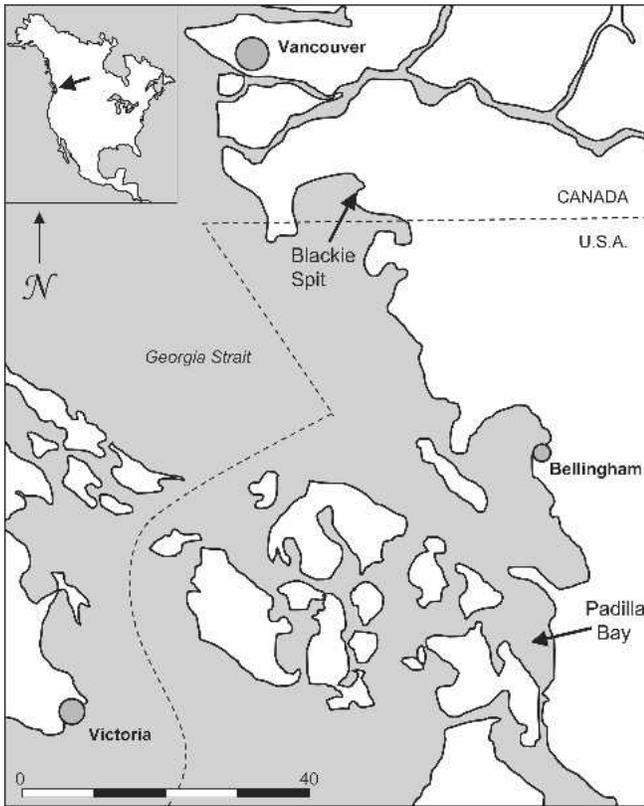


Figure 1. Collection sites for *Crepidula convexa*: Blackie Spit (49°04'N, 122°53'W), South Surrey, British Columbia, Canada, and Padilla Bay (48°28'N, 122°31'W), northern Puget Sound, Washington State, U.S.A. Scale in km.



Figure 2. Dorsal and ventral views of a shell of *Crepidula convexa* collected from the shell of an individual of *Batillaria cumingi* in Padilla Bay, March 2001. Shell length 12 mm.

grayish shells (Fig. 2) represent a morphology that is more common in populations of *C. convexa* from New England than in more southern populations of this species (Collin 2002). However, this morphology is also present in the southern populations of *C. convexa* and occurs in its sister species *C. ustulatulina* Collin, 2002. Therefore the samples from Washington could not be assigned to *C. convexa* with absolute certainty on the basis of their shells alone.

To confirm this identification genetically and to determine the source population, DNA was extracted from 2 specimens and 640 base pairs of cytochrome oxidase c subunit I (COI) were sequenced following the methods of Collin (2001). Neighbor-joining analysis of these new sequences (GenBank: AY615331, AY615332) in combination with sequences previously reported by Collin (2001) showed that the animals from Padilla Bay are indeed *Crepidula convexa* (Figure 3). The haplotypes from Padilla Bay are very similar to haplotypes of animals collected from Rhode Island and New Jersey. They clearly cluster with the samples from the northeastern United States to the exclusion of *C. convexa*

from Georgia, as does a previously sequenced animal from Blackie Spit, British Columbia. Development was not observed.

It is unclear when *Crepidula convexa* first appeared in the Pacific Northwest. It may have been introduced with imports of Atlantic oysters, *Crassostrea virginica*, which were common between the 1870s and 1930s (Carlton 1992, Wornham and Carlton 2005). It was first observed in Washington State more than 40 years later in Padilla Bay in 1970 on shell surfaces of *Batillaria cumingi* (Penttila 1971 and D. Penttila personal communication) but was not reported in regional surveys of the same time period (Sylvester and Clogston 1958, Jeffrey 1976, Carlton 1979, 1992). Since 1999 it has been observed in Padilla Bay at densities of up to 30/m² (O'Connor *et al.* 2002). In British Columbia, *C. convexa* was first collected in 1988 at Blackie Spit in Boundary Bay (R. Forsyth in Carlton 1992, Collin 2001) (Figure 1). We are not aware of established populations elsewhere in the Pacific Northwest, including San Juan Island, Washington (M. Dethier, personal communication). It is not known whether the

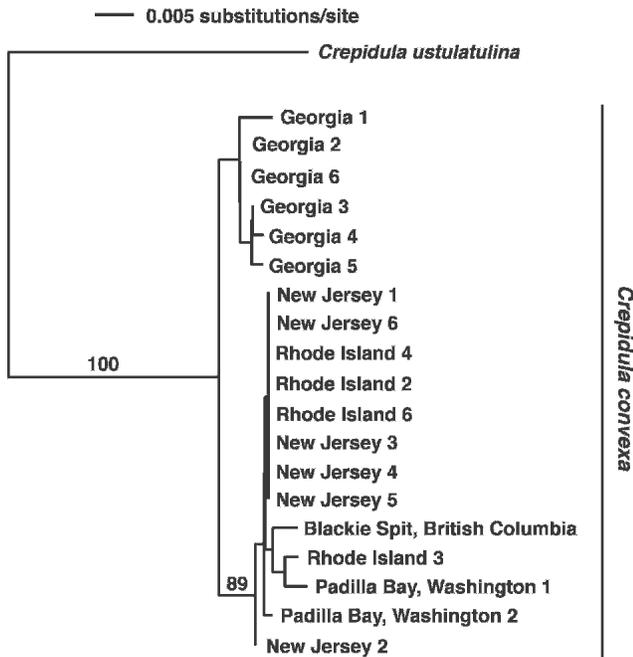


Figure 3. Neighbor-joining tree of 640 bp of COI sequence data from *Crepidula convexa*. Bootstrap percentages greater than 70% are indicated above the branches.

current populations of *C. convexa* in the Pacific Northwest represent the spread from a single introduction or sites of multiple introductions, since Atlantic oysters were planted in numerous locations throughout the region (Carlton 1979, Wonham and Carlton 2005).

Although identification of introduced calyptraeids has not always been clear-cut (e.g., the initial misidentification of *Crepidula onyx* as *Crepidula fornicata* in Asia), the situation on the west coast of North America is relatively straightforward. Members of the introduced species *C. fornicata* can be distinguished from members of the similar native species *C. onyx* on the basis of shell morphology and body pigmentation and is not easily confused with any other west coast species. Members of *Crepidula convexa* can also be distinguished from members of native Pacific species on the basis of morphology, but can be confused with both *Crepidula maculosa* (Conrad, 1846) and *Crepidula ustulatulina* from the southeast coast of North America. Neither of these species has been reported from the west coast of North America. The reports of introductions of *Crepidula plana* Say, 1822 are more difficult to verify. *Crepidula plana* is more or less morphologically indistinguishable from its close relative from the Atlantic *Crepidula depressa* Say, 1822 (Collin 2000), although this species generally occurs in warmer water. Additionally, *C. plana* cannot be distinguished from the Pacific species *Crepidula perforans* Valenciennes, 1846, *Crepidula*

williamsi Coe, 1947, *Crepidula fimbriata* Reeve, 1859, and *Crepidula explanata* Gould, 1853 or from any of the flat white species of *Crepidula* from other parts of the world with any certainty without the aid of developmental and DNA sequence data. There are no reported introductions of calyptraeids on the Atlantic coast of North America.

ACKNOWLEDGMENTS

We are grateful to M. O'Connor, S. Riggs, and C. Harley for collection assistance and to J. T. Carlton for initial morphological identification of *Crepidula convexa* from Padilla Bay and J. T. Carlton and D. Franz for helpful comments.

REFERENCES

Blanchard, M. 1997. Spread of the slipper limpet *Crepidula fornicata* (L. 1758) in Europe: Current state and consequences. *Scientia Marina* **61** (Supplement 9): 109-118.

Carlton, J. T. 1979. History, Biogeography, and Ecology of the Introduced Marine and Estuarine Invertebrates of the Pacific Coast of North America. Ph. D. thesis. University of California, Davis.

Carlton, J. T. 1992. Introduced marine and estuarine mollusks of North America: An end-of-the-20th-century perspective. *Journal of Shellfish Research* **11**: 489-505.

Choe, B. L. and J. K. Park. 1992. Nine unrecorded mesogastropodous species (Gastropoda: Mollusca) from Korean waters—superfamilies Turritellacea, Calyptraeacea, Cypraeaacea, and Tonnacea. *Korean Journal of Malacology* **8**: 29-40.

Collin, R. 2000. Phylogeny of the *Crepidula plana* (Gastropoda: Calyptraeidea) cryptic species complex in North America. *Canadian Journal of Zoology* **78**: 1500-1514.

Collin, R. 2001. The effects of mode of development on phylogeography and population structure of North Atlantic *Crepidula* (Gastropoda: Calyptraeidae). *Molecular Ecology* **10**: 2249-2262.

Collin, R. 2002. Another last word on *Crepidula convexa* and a description of *C. ustulatulina* sp. nov. (Gastropoda: Calyptraeidae) from the Gulf of Mexico. *Bulletin of Marine Science* **70**: 177-184.

Collin, R. 2005. Development, phylogeny, and taxonomy of *Bostrycapulus* (Caenogastropoda: Calyptraeidae), an ancient cryptic radiation. *Zoological Journal of the Linnean Society* **144**: 75-101.

Ekawa, K. 1985. Distribution and dispersion of *Crepidula onyx* in Japan. *Chiribotan* **16**: 37-44.

Jeffrey, R. 1976. A preliminary inventory of the biota of Padilla Bay. Washington State Department of Game. Reprinted October 1990 as *Padilla Bay National Estuarine Research Reserve Reprint Series* No. 1, Mount Vernon, Washington. 38 pp.

Minchin, D., D. McGrath, and C. B. Duggan. 1995. The slipper limpet, *Crepidula fornicata* (L.), in Irish waters, with a review of its occurrence in the north-eastern Atlantic. *Journal of Conchology* **35**: 247-254.

- Morton, B. 1987. Recent marine introductions into Hong Kong. *Bulletin of Marine Science* **41**: 503-513.
- O'Connor, M., M. Wonham, and C. Harley. 2002. Quantifying the impacts of an invader: The Asian mud snail *Batillaria attramentaria* on the mud flats of Padilla Bay, Washington. Washington State Department of Ecology (Publication No. 02-06-016). Available as *Padilla Bay National Estuarine Research Reserve Technical Report* No. 25, Mount Vernon, Washington.
- Penttila, D. 1971. Introduced marine mollusks of Washington and Oregon: A critical essay in partial fulfillment of the requirements for a Master of Science Degree in Biology. Unpublished document available at Oregon Institute of Marine Biology Library.
- Sylvester, R. O. and F. L. Clogston. 1958. A study of the preoperational marine environment in the vicinity of the Texas Company Refinery Puget Sound Works, Anacortes, Washington, for the Texas Company. Seattle. Available from the Library of the University of Washington, Seattle, Washington, and summarized in Jeffrey (1976).
- Woodruff, D. S., L. L. McMeekin, M. Mulvey, and M. P. Carpenter. 1986. Population genetics of *Crepidula onyx*: Variation in a Californian slipper snail recently established in China. *The Veliger* **29**: 53-63.
- Wonham, M. J. and J. T. Carlton. 2005. Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system. *Biological Invasions* **7**: 369-392.
- Zibrowius, H. 1992. Ongoing modifications of the Mediterranean marine fauna and flora by the establishment of exotic species. *Mésogée* **51**: 83-107.

Accepted: 19 January 2005