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Bivalve Superpower: The Global Invasion of Corbiculid Clams

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Corbiculidae is a family of clams which has the capability of invading habitats. Particularly, there are three genera (*Batissa*, *Polymesoda*, *Corbicula*) which are widely distributed all over the world. The genus *Batissa* territories are the tropical India and Indo-Pacific Region. *Polymesoda* species are tropical colonizers while Corbicula conquered all continents except Antarctica. Dispersal of the bivalves may take place by different media which includes animal, human and environmental phenomena. *C. fluminea* is the most successful invader with widest scope of distribution, worldwide. The invasion of corbiculid clams may bring apparent instability in the environment. Controlling the invasion is necessary to maintain the balance of nature.

Keywords: Biogeography; dispersal mechanism; bioinvasions; molluscs.

1. INTRODUCTION

Corbiculidae clams are burrowing in soft bottoms of shallow fresh or brackish water areas. They are suspension filter-feeders which are commonly found in marshes and mangroves. The name "*Corbicula*" (little basket) refers to their characteristic concentrically ribbed shells and genera shape. Freshwater corbiculids are ovoviviparous, brooding internally fertilized eggs

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in brood pouches [1]. Development via a free swimming larva is typically an attribute of brackish water corbiculids. Some corbiculid clams exhibit hermaphroditism [2,3] while others have separate sexes [4,5].

Members of the family Corbiculidae are capable of successfully invading aquatic environments [6,7]. These clams are characterized as resilient bivalve species because they possess biological attributes that allow them to overcome adverse environmental conditions or migrate and subsequently adapt in new environments [8-10]. Accordingly, one can consider the corbiculid clams as a “superpower” of the bivalve world.

The invasion of non-indigenous species is an imminent danger to the stability of aquatic biomes. Such species may modify the aquatic ecosystem structure and functioning affecting baseline abiotic conditions and the resident biota. Many bivalves are known to be successful invaders of aquatic habitats [11-14]. Bivalve invasions may considerably alter pre-existing populations by displacing native species through competitive interactions [11,15,16]. The undesirable effect of exotic macrofouling bivalves in different kinds of industrial facilities had been documented in molluscan studies [17,18,19]. Controlling of biological invasions is important to maintain the balance in the ecosystem.

This paper will review the biogeographical invasion of the corbiculid clams. In particular, this discusses the biology, global distribution, dispersal mechanisms and the bioinvasion controlling schemes of the family Corbiculidae.

2. THE CORBICULID AXIS POWER: THE BIOLOGY OF *Batissa*, *Polymesoda* AND *Corbicula*

There are three genera within the family Corbiculidae which are distributed worldwide, namely: *Batissa*, *Polymesoda* and *Corbicula*. These clams invaded aquatic ecosystems such as estuaries and rivers all over the world. Truly, they are the “Axis Power” of the family Corbiculidae. Their biological mechanisms serve as the battle gear in their successful invasion of habitats.

The genus *Batissa* is represented by the species *B. violacea* (Fig. 1). This bivalve species is a tropical free-living clam with an average growth rate of 20 mm per year [20]. The reported maximum size for this clam ranged from 120-150 mm shell length which corresponds to age 6-7.5 years [8,21]. It burrows to approximately 100-150 mm of the soft substrate [20]. This activity is an adaptive strategy used to gain access to water from moist sediments during droughts. The clam has the biological capacity for considerable movement [20]. *B. violacea* can migrate and survive in estuarine and lacustrine environments [8].

Photo credits: Joop Trausel and Frans Slieker

Fig. 1. *Batissa violacea*

Polymesoda species (Fig. 2) are composed of freshwater [2,22] and brakishwater [23-26] inhabitants. These clams are suspensivore and saprophytic [27] and were postulated to be *K*-strategists [24]. *Polymesoda* exhibits aerial respiration as an adaptation for long periods of emersion [26,28,29]. The bivalves burrow in muddy substrates and thrive in mangroves and high intertidal areas [10,26,30]. These clams can also survive in highly turbid waters [31].

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Fig. 2. *Polymesoda* species

Members of the genus *Corbicula* (Fig. 3) are inland water filter-feeding bivalves with globular shells. These clams have the capability of collecting food in sediments with their extendable foot. Most *Corbicula* species are hermaphrodite releasing a brooded non-swimming pediveliger stage at 200 µm length [32]. These bivalve species are tolerant to aerial exposure for weeks but intolerant to low oxygen levels [33]. The clams invade areas such as oligotrophic to eutrophic flowing streams, rivers and lakes on oxygenated muddy to sandy sediments [33]. *Corbicula* species can tolerate temperature range of 2-34℃ [34] and salinity range of 5-14 ppt [35].

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Fig. 3. *Corbicula* species

3. THE CORBICULID EMPIRE: THE BIOGEOGRAPHY OF FAMILY CORBICULIDAE

3.1 The *Batissa* Territories

B. violacea is the only member of the genus *Batissa*. It appears that the distribution of this clam is concentrated in the tropical India and Indo-Pacific region (Fig. 4). Particularly, *B. violacea* are found in Fiji [20], India [36,37], Philippines [38], Indonesia [39] and Papua New Guinea [40].

3.2 *Polymesoda*: Tropical Colonizer

Based on literatures, there are at least eight species of *Polymesoda* globally, namely: *P. bengalensis*, *P. caroliniana*, *P. coaxans*, *P. erosa*, *P. expansa*, *P. inflata*, *P. radiata* and *P. solida*. The distribution of these species appears being restricted to the tropical Central America and Indo-Pacific regions (Fig. 5). Specifically, *Polymesoda* species are found in Australia [10], Colombia [2], Costa Rica [41], Hong Kong [24], India [30], Indonesia [42], Japan [43], Malaysia [44], Mexico [27], Philippines [45-47], Singapore [26], Thailand [48] and USA [29].

Fig. 4. Tropical indo-pacific distribution of *B. violacea*

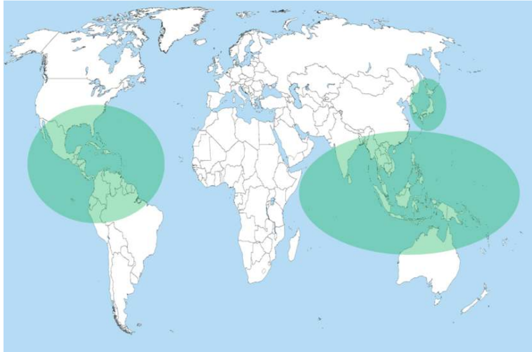

Fig. 5. Tropical Central America and indo-pacific distribution of genus *Polymesoda*

3.3 *Corbicula*: The World Conquerors

There are at least ten species of genus *Corbicula* distributed globally. Among these species are *C. australis*, *C. fluminalis*, *C. fluminea*, *C. japonica*, *C. loehensis*, *C. linduensis*, *C. madagascariensis*, *C. matannensis*, *C. moltkiana* and *C. possoensis*. The distribution of *Corbicula* species is worldwide (Fig. 6). In particular, members of the genus can be found in Argentina [49], Australia [50], France [9], Germany [51], Indonesia [1], Japan [4], Madagascar [7], Poland [52], Philippines [53], Spain [54] and USA [55]. *C. fluminea* is the most successful invader in the family as its distribution covers all continents except Antarctica.

Based on the distribution of the three corbiculid genera, it appeared that the Indo-Pacific region has the most diversity of clams (Fig. 7). This suggests that the said region is where the corbiculid clams originate. This also implies that the area has the ideal environmental condition for the three genera to coexist. Nonetheless, the distribution of these genera only shows the capability of the clams to invade habitats.

Fig. 6. Global distribution of the genus *Corbicula*

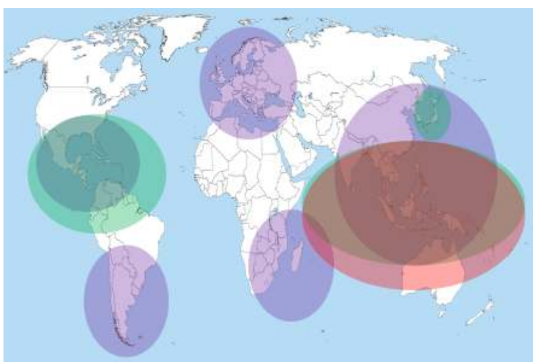

Fig. 7. Global distribution of family *Corbiculidae*

4. THE MAKING OF AN EMPIRE: DISPERSAL MECHANISMS

An invasive species should have several characteristics to be successful in the new environment: A short life; rapid growth, rapid sexual maturity; high fecundity; euryoecious; eurytopic; gregarious behavior; some form of association with human activities; wide genetic variability and phylogenetic plasticity; suspension feeding; and ability to repopulate previously colonized habitat [56]. Most of these characteristics are present in the corbiculid clams. It is clear that the corbiculid clams are capable of invading habitats worldwide. The question now is how did these clams disperse globally from its origin? Various literatures are available and may answer this question. It appeared that there are three vectors of dispersal from their origins: Animals, humans and environmental phenomena.

There is no direct studies on corbiculidae with regard to dispersal via animal vector. However, Voelz et al. [57] reported that *C. fluminea* moved upstream at a rate 1.2 km yr^{-1} in a southeastern U.S. black water stream unaided by humans. Hence, they speculated that fish may have been partially responsible for dispersing the clams. Another possibility of animal vector dispersal is the water fouls. According to McMahon [33], the pediveliger and juveniles of the corbiculid clams may have been transported on the feet or feathers of aquatic birds.

Anthropogenic transportation is the most likely explanation for the global dispersal of these clams. Foster et al. [58] reported that *C. fluminea* first entered the United States as a food item. Counts [59] accounted the spread of corbiculid clams primarily by human activities such as bait bucket introductions and accidental introductions associated with imported aquaculture species. Other human-induced dispersals are by ballast water transport, aquarium releases, transport of juveniles and/or adults as a tourist curiosity and the juvenile byssal attachment to boat hulls [60].

Flooding and the flow of water current are the environmental phenomena responsible for the dispersal of corbiculid clams. McMahon [33] attributed the extraordinary dispersal capacities of corbiculid pediveliger and juvenile to their small size and mass. This allows them to remain suspended for long distances in even minimally turbulent water. Kraemer [61] reported that juvenile corbiculid clams are transported by water currents using their single long byssal thread which acts as a drag line. According to McMahon [33], channelization of waterways for flood control or navigation increases flow velocities and turbulence, this will improve the condition for dispersal of *C. fluminea*.

Hoyer et al. [62] developed a model to investigate the passive dispersal of planktonic larvae. The model was a three-dimensional (3D) Lagrangian, individual-based dispersion model. This larval dispersion model highlighted the importance of waves and currents in the dispersal and colonization of invasive species. The model was applied in the dispersion of *C. fluminea* larvae in a large, deep lake [63]. *C. fluminea* larvae dispersal was determined by the magnitude and timing of strong wind events.

Larvae are carried away from the original areas along a discrete number of dispersal pathways. Colonization of new habitats outside the larvae origin is low and sensitive to the larvae settling velocity.

5. THE AFTERMATH: IMPACTS OF INVASION

The impact of corbiculid clams on the endemic bivalve inhabitants transpire mainly when major die-offs occur. In most cases, the non-indigenous corbiculids and other indigenous bivalves coexist [64]. However, several adverse effects have been reported. Clarke [65] reported negative impacts of *Corbicula* on native unionids in the Tar River system, Virginia. Buchanan [66] reported high mortality of endemic unionid mussels after die-offs of *Corbicula* in Bourbeuse and Meramec rivers, Missouri. Scheller [67] attributed die-offs of native clams population crashes of *Corbicula*, which during putrefaction release ammonia and reduce dissolved oxygen in the sediment. In a two-year ecological study, Sickel [68] reported that corbiculid clams did not appear to be affecting adult native clams directly; however, they may be excluding the juveniles, which may result in the loss of many endemic species.

The corbiculids have high rates of filtration and their abundances make them a major consumer of phytoplankton [30]. These clams decreased phytoplankton and chlorophyll *a* concentrations in the Potomac River by 20–75% [69]. Similar seston reductions by *Corbicula fluminea* occurred in the Chowan River [70], Savannah River [71], and other lotic systems [72]. The removal of seston by corbiculid clams has changed the zooplankton population by increasing the density of copepods and decreasing that of the rotifers in some systems [64]. Hass et al. [73] claimed that the mass invasion by *Corbicula* sp. strongly affected ecosystem functions by linking pelagic and benthic processes by their intense filter feeding activity and thereby enhance the capacity for self-purification of the river system. Hakenkamp and Palmer [55] found that *Corbicula* consumed significant quantities of organic material in the streambed when conditions favored pedal feeding but increased buried organic matter stores when filter feeding promoted deposition of organic matter as feces and pseudofeces. These clams contributed considerably to total benthic community respiration, and used pedal feeding on benthic organic material to grow at a faster rate than that possible by filter feeding alone [6].

The corbiculid clam's greatest economic impact has been macrofouling of raw water systems in fossil-fueled or nuclear power stations [74,75]. Even though the planktonic stage is short-lived, the non-swimming and settling pediveligers and juveniles enter the facility through the intakes, then through traveling screen and strainers [76]. Accumulations of adult shells also reduce flow velocities below the threshold for settlement, promoting accumulations of silt and sand in which clams burrow [77].

Positive effects of corbiculid clams were also observed. Empty shells of *C. fluminea* serve as shelter and substrate for other organisms [78,79]. These clams are also food resource for other pelagic and benthic species [80]. Members of family Corbiculidae were also reported as good bioindicator species for ecotoxicological studies [81,82].

6. CONQUERING THE CONQUERORS: CONTROLLING BIOINVASIONS

Mackie and Claudi [83] discussed some mitigation for controlling the bioinvasions of corbiculid clams. Prevention is still the best method to control the invasion of the clams. To eliminate the source of many introductions, navigation and dredging activities should be regulated. Thermal regulation is one technique to eliminate corbiculids in water pipes. In this method, water in the pipes is heated to temperatures exceeding 37℃. There are also mechanical methods that can be employed. For example, corbiculids may be removed from piping by passing wads under pressure. One can also use screens and shell traps to reduce impacts. Chemical methods are also options that may be considered in the elimination of invasive corbiculids. There are oxidizing molluscicides which may significantly reduce the corbiculid invasions if applied with water at 40℃. Oxygen depletion is also a chemical technique in controlling the invasion of corbiculids.

Reported natural predators of Corbiculidae are crabs and fish [24,84]. However, as of today, no species-specific biological control was developed for the eradication of the invasive members of family Corbiculidae. Nevertheless, some corbiculid clams showed reduced anti-predation behaviors in low dissolved oxygen levels [85].

Covich et al. [86] proposed the control of *Corbicula* population density using crayfish.

7. CONCLUSION

The biogeography of corbiculid clams showed worldwide distribution. This only implies the ability of these bivalves to adapt and invade different types of environment. Their resiliency to different environmental conditions is due to their biological characteristics. The invasions of these clams affect the community structure of the native inhabitants which may lead to the loss of biodiversity. Preventing introductions of these bivalves is the best method of controlling the invasions.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Korniushin AV, Glaubrecht M. Novel reproductive modes in freshwater clams: brooding and larval morphology in Southeast Asian taxa of *Corbicula* (*Mollusca: Bivalvia: Corbiculidae*). Acta Zool 2003;84:293-315.
2. Rueda H, Urban HJ. Population dynamics and fishery of the fresh-water clam *Polymesoda solida* (*Corbiculidae*) in Cienaga Poza Verde, Salamanca Island, Colombian Caribbean. Fish Res. 1998;39:75-86.
3. Ishibashi R, Ookubo K, Aoki M, Utaki M, Komaru A, Kawamura K. Androgenetic reproduction in a freshwater diploid clam *Corbicula fluminea* (*Bivalvia: Corbiculidae*). Zool Sci. 2003;20:727-732.
4. Nanbu R, Mizuno T, Sekiguchi H. Post-settlement growth and mortality of brackishwater clam *Corbicula japonica* in the Kiso estuaries, Central Japan. Fish Sci 2008;74:1254-1268.
5. Clemente S, Ingole B. Gametogenic development and spawning of the mud clam, *Polymesoda erosa* (Solander, 1876) at Chorao Island, Goa. Mar Biol Res. 2009;5:109-121.
6. Hakenkamp CC, Ribblett SG, Palmer MA, Swan CM, Reid JW, Goodison MR. The impact of an introduced bivalve (*Corbicula fluminea*) on the benthos of a sandy stream. Freshwater Biol. 2001;46:491-501.
7. Glaubrecht M, Feher Z, Von Rintelen T. Brooding in *Corbicula madagascariensis* (*Bivalvia, Corbiculidae*) and the repeated evolution of viviparity in corbiculids. Zool Scr. 2006;35:641-654.
8. Morton B. The functional morphology of the organs of the mantle cavity of *Batissa violacea* (Lamark, 1797) (*Bivalvia: Corbiculacea*). Am Malacol Bull. 1989; 7(1):73-79.
9. Mouthon J. Life cycle and population dynamics of the Asian clam *Corbicula fluminea* (*Bivalvia: Corbiculidae*) in the Saone River at Lyon (France). Hydrobiologia. 2001;452:109-119.
10. Gimin R, Mohan R, Thinh LV, Griffiths AD. 2004. The relationship of shell dimensions and shell volume to live weight and soft tissue weight in the mangrove clam, *Polymesoda erosa* (Solander, 1786) from northern Australia. NAGA, World Fish Center Quarterly. 2004;27(3,4):32-35.
11. Ricciardi A, Whoriskey FG, Rasmussen JB. Impact of the *Dreissena* invasion on native unionid bivalves in the upper St. Lawrence River. Can J Fish Aquat Sci. 1996;53:1434-1444.
12. Karatayev AY, Burlakova LE, Padilla DK, Johnson LE. Patterns of spread of the zebra mussel (*Dreissena polymorpha* (Pallas)): The continuing invasion of Belarussian lakes. Biol Invasions 2003;5:213-221.
13. Sousa R, Gutierrez JL, Aldridge DC. Non-indigenous invasive bivalves as ecosystem engineers. Biol Invasions. 2009;11:2367-2385.
14. Douda K, Vrtilek M, Slavik O, Reichard M. The role of host specificity in explaining the invasion success of the freshwater mussel *Anodonta woodiana* in Europe. Biol Invasions. 2012;14:127-137.
15. Pace ML, Findlay SEG, Fischer D. Effects of an invasive bivalve on the zooplankton community of the Hudson River. Freshwater Biol. 1998;39:103-116.
16. Strayer DL, Hattala KA, Kahnie AW. Effects of an invasive bivalve (*Dreissena polymorpha*) on fish in the Hudson River estuary. Can J Fish Aquat Sci. 2004;61:924-941.
17. Brugnoli E, Clemente J, Boccardi L, Borthagaray A, Scarabino F. Golden mussel *Limnoperna fortune* (*Bivalvia: Mytilidae*) distribution in the main hydrographical basins of Uruguay: Update

and predictions. An Acad Bras Cienc. 2005;77(2):235-244.
18. Lopes MN, Vieira JP, Burns MDM. Biofouling of the golden mussel *Limnoperna fortune* (Dunker, 1857) over the Anomura crab *Aegle platensis* Schmitt, 1942. Pan-Am J Aquat Sci. 2009;4(2):222-225.
19. Kennedy VS. The invasive dark false mussel *Mytilopsis leucophaeata* (*Bivalvia: Dressenidae*): A literature review. Aquat Ecol. 2011;45:163-183.
20. Ledua E, Matoto SV, Sesewa A, Korovulavula J. Freshwater clam resource assessment of the Bai River. SPC Integrated Coastal Fisheries Management Project Reports Series #1; 1996.
21. Lamprey K, Healy J. Bivalves of Australia. Leiden: Backhuys Publishers. 1998;2.
22. Aristizabal MVD. Condicion somatic de la almeja *Polymesoda solida* (*Veneroidea: Corbiculidae*) durante el period lluvioso, en el Parque Natural Isla de Salamanca, Caribe colombiano. Rev Biol Trop. 2010;58(1):131-145.
23. Gray EMD, Hackney CT. Seasonal and spatial distribution of the carolina marsh clam *Polymesoda caroliniana* (Bosc) in a Mississippi tidal marsh. Estuaries. 1982;5(2):102-109.
24. Morton B. The population structure and age of *Polymesoda* (*Geloina*) *erosa* (*Bivalvia: Corbiculacea*) from a Hong Kong mangrove. Asian Mar Biol. 1988;5:107-113.
25. Ingole BS, Naik S, Furtado R, Ansari ZA, Chatterji A. Population characteristics of the mangrove clam *Polymesoda* (*Geloina*) *erosa* (Solander, 1786) in the Chorao mangrove, Goa. Proceedings of the National Conference on Coastal Agriculture, Goa, India; 2002.
26. Hiong KC, Peh WYX, Loong AM, Wong WP, Chew SF, Ip YK. Exposure to air, but not seawater, increases the glutamine content and the glutamine synthetase activity in the marsh clam *Polymesoda expansa*. J Exp Biol. 2004;207:4605-4614.
27. Kusunoki ATW, MacKenzie Jr CL. Rangia and marsh clams, *Rangia cuneata*, *R. flexuosa*, and *Polymesoda caroliniana*, in Eastern Mexico: Distribution, biology and ecology, and historical fisheries. Mar Fish Rev. 2004;66(3):13-20.
28. Morton B. The biology and functional morphology of the Southeast Asian mangrove bivalve, *Polymesoda* (*Geloina*) *erosa* (Solander, 1786) (*Bivalvia: Corbiculidae*). Can J Zool. 1976;54(4):482-500.
29. Deaton LE. Oxygen uptake and heart rate of the clam *Polymesoda caroliniana* bosc in air and in seawater. J Exp Mar Biol Ecol. 1991;147:1-7.
30. Clemente S, Ingole B. Recruitment of mud clam *Polymesoda erosa* (Solander, 1876) in a mangrove habitat of Chorao Island, Goa. Braz J Oceanogr. 2011;59(2):153-162.
31. Argente FAT, Cesar SA, Dy DT. High turbidity affects filtration rate and pseudofaeces production of the mud clam, *Polymesoda erosa* (Solander 1786) (*Bivalvia: Corbiculidae*). Biotropia 2014;21(2):71-81.
32. Prezani RS, Chalermwat K. Flotation of the bivalve *Corbicula fluminea* as a means of dispersal. Science. 1984;225:1491-1493.
33. McMahon RF. Invasive characteristics of the freshwater bivalve *Corbicula fluminea*. In: Claudi R, Leach J, editors. Non-Indigenous Freshwater Organisms: Vectors, Biology and Impacts; 2000.
34. Janech MG, Hunter RD. *Corbicula fluminea* in a Michigan River: Implications for low temperature tolerance. Malacol Rev. 1995;28:199-124.
35. Morton B, Tong, KY. The salinity tolerance of *Corbicula fluminea* (*Bivalvia: Corbiculoidea*) from Hong Kong. Malacol Rev. 1985;18:91-95.
36. Hatha AAM, Christi KS, Singh R, Kumar S. Bacteriology of the fresh water bivalve clam *Batissa violacea* (Kai) sold in the Suva market. S Pac J Nat Sci. 2005;23:48-50.
37. Ghosh D. Mangroves: The most fragile ecosystem. Resonance. 2011;16(1):47-60.
38. Magura BZ. Distribution, population structure, biomass and exploitation of *Batissa violacea* (*Bivalvia: Corbiculidae*) along Babuyan River, Puerto Princesa City, Palawan, Philippines. J Aquat Sci. 2006;3:66-73.
39. Zulkifli Y, Alitheen NB, Son R, Raha AR, Samuel L, Yeap SK, Nishibuchi M. Random amplified polymorphic DNA-PCR and ERIC PCR analysis on *Vibrio parahaemolyticus* isolated from cockles in Padang, Indonesia. Int Food Res J. 2009;16:141-150.
40. Thangavelu A, David B, Barker B, Gineste JM, Delannoy JJ, Lamb L, Araho N, Skelly R. Morphometric analyses of *Batissa*

violacea shells from Emo (OAC), Gulf Province, Papua New Guinea. Archeol Ocean. 2011;46:67-75.

41. Campos ER, Peña JC, Cruz RA, Palacios JA. Crecimiento y ciclo reproductive de *Polymesoda radiata* (*Bivalvia: Corbiculidae*) en Costa Rica. Rev Biol Trop. 1998;46(3):643-648.
42. Nordhaus I, Hadipudjana FA, Janssen R, Pamungkas J. Spatio-temporal variation of macrobenthic communities in the mangrove-fringed Segara Anakan Lagoon, Indonesia, affected by anthropogenic activities. Reg Environ Change. 2009;9:291-313.
43. Bachok Z, Mfilinge PL, Tsuchiya M. The diet of the mud clam *Geloina coaxans* (*Mollusca, Bivalvia*) as indicated by fatty acid markers in a subtropical mangrove forest of Okinawa, Japan. J Exp Mar Biol Ecol. 2003;292:187-197.
44. Hamli H, Idris MH, Abu Hena MK, Wong SK. Taxonomic study of edible bivalve from selected division of Sarawak, Malaysia. Int J Zool Res. 2012;8(1):52-58.
45. Masagca JT, Mendoza AV, Tribiana ET. The status of mollusk diversity and physical setting of the mangrove zones in Catanduanes Island, Luzon, Philippines. Biotropia. 2010;17(2):62-76.
46. Dolorosa RG, Galon FD. Population dynamics of the mangrove clam *Polymesoda erosa* (*Bivalvia: Corbiculidae*) in Iwahig, Palawan, Philippines. Int J Fauna Biol Stud. 2014;1(6):11-15.
47. Argente FAT, Ilano AS. Susceptibility of some pathogenic microbes to soft tissue extract of the mud clam, *Polymesoda expansa* (*Bivalvia: Corbiculidae*). The Experiment. 2015;30(2):1984-1990.
48. Printrakoon C, Wells FE, Chitramvong Y. Distribution of molluscs in mangroves at six sites in the upper Gulf of Thailand. Raffles B Zool. 2008;18:247-257.
49. Caltado DH, Boltovskoy D, Stripeikis J, Pose M. Condition index and growth rates of field caged *Corbicula fluminea* (Bivalvia) as biomarkers of pollution gradients in Parana River delta (Argentina). Aquat Ecosyst Health Manage. 2001;4:187-201.
50. Byrne M, Phelps H, Church T, Adair V, Selvakumaraswamy P, Potts J. Reproduction and development of the freshwater clam *Corbicula australis* in southeast Australia. Hydrobiologia. 2000;418:185-197.
51. Weitere M, Vohmann A, Schulz N, Linn C, Dietrich D, Arndt H. Linking environmental warming to fitness of the invasive clam *Corbicula fluminea*. Glob Change Biol. 2009;15:2838-2851.
52. Skuza L, Labecka AM, Domagala J. Cytogenetic and morphological characterization of *Corbicula fluminalis* (O.F. Muller, 1774) (*Bivalvia: Veneroida: Corbiculidae*): Taxonomic status assessment of a freshwater clam. Folia Biol. 2009;57(3-4):177-185.
53. Beltran KS, Pocsidio GN. Acetylcholinesterase activity in *Corbicula fluminea* Mull., as a biomarker of organophosphate pesticide pollution in Pinacanauan River, Philippines. Environ Monit Assess. 2010;165:331-340.
54. Araujo R, Moreno D, Ramos MA. The Asiatic clam *Corbicula fluminea* (Muller, 1774) (*Bivalvia: Corbiculidae*) in Europe. Am Malacol Bull. 1993;10(1):39-49.
55. Hakenkamp CC, Palmer, MA. Introduced bivalves in freshwater ecosystems: The impact of *Corbicula* on organic matter dynamics in a sandy stream. Oecologia. 1999;119:445-451.
56. Morton B. The aquatic nuisance species: A global perspective and review. In: D'itri E, editor. Zebra mussels and other aquatic species. Michigan: Ann Arbor Press; 1996.
57. Voelz NJ, McArthur JV, Rader RB. Upstream mobility of the Asiatic clam *Corbicula fluminea*: Identifying potential dispersal agents. J Freshwater Ecol. 1998;13:39-45.
58. Foster AM, Fuller P, Benson A, Constant S, Raikow D. *Corbicula fluminea*. USGS Non-indigenous Aquatic Species Database, Gainesville, Florida; 2008.
59. Counts CL. The zoogeography and history of the invasion of the United States by *Corbicula fluminea* (*Bivalvia: Corbiculidae*). Am Malacol Bull. 1986;2:7-39.
60. Sousa R, Antunes C, Guilhermino L. Ecology of the invasive Asian clam *Corbicula fluminea* (Muller, 1774) in aquatic ecosystems: An overview. Ann Limnol-Int J Lim. 2008;44(2):85-94.
61. Kraemer LR. Juvenile *Corbicula*: Their distribution in Arkansas River benthos. In: Britton JC, editor. Proceedings of the First International *Corbicula* Symposium; 1979.
62. Hoyer AB, Wittmann ME, Chandra S, Schladow SG, Rueda FJ. A 3D individual-based aquatic transport model for the assessment of the potential dispersal of

planktonic larvae of an invasive bivalve. J Environ Manage. 2014;145:330-340.

63. Hoyer AB, Schladow SG, Rueda FJ. Local dispersion of nonmotile invasive bivalve species by wind-driven lake currents. Limnol Oceanogr; 2015.
DOI: 10.1002/lno.10046

64. Beaver RJ, Crisman TL, Brock RJ. Grazing effects of an exotic bivalve (*Corbicula fluminea*) on hypereutrophic lake water. Lake Reserv Manage. 1991;7(1):45-51.

65. Clarke AH. Freshwater molluscan survey of the Roanoke, Tar and Neuse River systems, N.C. Am Malacol Bull. 1984;3:104-105.

66. Buchanan AC. Die-off impacts on the mussel fauna of selected reaches of the Bourbeuse and Meramec Rivers, Missouri. In: Neves RJ. Proceedings of the Workshop on Dieoffs of Freshwater Mussels in the United States; 1987.

67. Scheller JL. The effect of die-offs of Asian clams (*Corbicula fluminea*) on native freshwater mussels (Unionidae). Thesis MS. Virginia Polytechnic Institute and State University, Blacksburg; 1997.

68. Sickel JB. An ecological study of the Asiatic clam, *Corbicula manilensis* (Philippi, 1841), in the Altamaha River, Georgia, with emphasis on population dynamics, productivity and control methods. Ph.D. Dissertation. Emory University, Atlanta; 1976.

69. Cohen RH, Dresler PV, Phlips EJP, Cory RL. The effect of the Asiatic clam, *Corbicula fluminea,* on phytoplankton of the Potomac River, Maryland. Limnol Oceanogr. 1984;29:170-180.

70. Lauritsen DD. Filter-feeding in *Corbicula fluminea* and its effects on seston removal. J N Am Benthol Soc. 986;5:165-172.

71. Leff LG, Burch JL, McArthur JV. Spatial distribution, seston removal, and potential competitive interactions of the bivalves *Corbicula fluminea* and *Elliptio complanata*, in a coastal plain stream. Freshwater Biol. 1990;24:409-416.

72. McMahon RF, Williams CJ. A reassessment of growth rate, life span, life cycles and population dynamics in a natural population and field cages individuals of *Corbicula fluminea* (Muller) (*Bivalvia: Corbiculacea*). Am Malacol Bull. 1986;2:151-166.

73. Haas G, Brunke M, Streit B. Fast turnover in dominance of exotic species in the Rhine River determines biodiversity and ecosystem function: An affair between amphipods and mussels. In: Leppakoski E, Gollasch S, Olenin S. Invasive Aquatic Species of Europe: Distribution, Impacts and Management; 2002.

74. McMahon RF. Ecology of an invasive pest bivalve: *Corbicula fluminea*. In: Russell-Hunter WD, editor. The Molluscs, Ecology. New York: Academic Press. 1983;6.

75. McMahon RF, Bogan AE. Mollusca: Bivalvia. In: Thorp JH, Covich AP, editors. Ecology and classification of North American freshwater invertebrates, 2nd edition. San Diego: Academic Press; 2001.

76. Page TL, Neitzel A, Simmons MA, Hayes PF. Biofouling of power plant service systems by *Corbicula*. In: Proceedings of Second International *Corbicula* Symposium, Special Edition No. 2; 1986.

77. Smithson JA. Development of a *Corbicula* control treatment at the Baldwin power station. Am Malacol Bull. 1986;2:63-67.

78. Crooks JA. Characterizing ecosystem-level consequences of biological invasions: The role of ecosystem engineers. Oikos. 2002;97:153-166.

79. Gutiérrez JL, Jones CG, Strayer DL, Iribarne OO. Mollusks as ecosystem engineers: The role of shell production in aquatic habitats. Oikos. 2003;101:79-90.

80. Cantanhêde G, Hahn NS, Gubiani ÉA, Fugi R. Invasive molluscs in the diet of *Pterodoras granulosus* (Valenciennes, 1821) (Pisces, *Doradidae*) in the upper Paraná River floodplain, Brazil. Ecol Freshw Fish. 2008;17:47-53.

81. Caltado D, Colombo JC, Boltovskoy D, Bilos C, Landoni P. Environmental toxicity assessment in the Paraná River delta (Argentina): Simultaneous evaluation of selected pollutants and mortality rates of *Corbicula fluminea* (Bivalvia) early juveniles. Environ Pollut. 2001;112:379-389.

82. Yap CK, Edward FB, Tan SG. Concentrations of heavy metals in different tissues of the bivalve *Polymesoda erosa*: its potentials as a biomonitor and food safety concern. Pertanika J Trop Agric Sci. 2014;37(1):19-38.

83. Mackie GL, Claudi R. Monitoring and control of macrofaouling mollusks in fresh

water systems, 2nd edition. New York: Taylor and Francis Group; 2010.
84. Robinson JV, Wellborn GA. Ecological resistance to the invasion of a freshwater clam, *Corbicula fluminea*: Fish predation effects. Oecologia. 1988;77(4):445-452.
85. Saloom ME, Duncan RS. Low dissolved oxygen levels reduce anti-predation behaviors of the freshwater clam *Corbicula fluminea*. Freshw Biol. 2005;50:1233-1238.
86. Covich AP, Dye LL, Mattice JS. Crayfish predation on *Corbicula* under laboratory conditions. Am Midl Nat. 1981;105(1):181-188.

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