

Research Article

Hydroids (Cnidaria: Hydrozoa) from Japanese tsunami marine debris washing ashore in the northwestern United States

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Received: 12 February 2014 / Accepted: 28 May 2014 / Published online: 4 August 2014

Handling editor: Melissa Frey

Abstract

Fourteen species of hydroids, including two anthoathecates and 12 leptothecates, are reported from the west coast of North America on debris from the tsunami that struck Japan on 11 March 2011. Six species were found on a dock that stranded at Agate Beach, Newport, Oregon, five from a boat at Gleneden Beach, Oregon, four from a dock in Olympic National Park, Washington, and two from a boat in Grays Harbor, Washington. *Obelia griffini* Calkins, 1899, the most frequently encountered species, was collected on three of the four derelict substrates. Eight of the species are known to be amphi-Pacific in distribution. Of the rest, at least five (*Stylactaria* sp.; *Eutima japonica* Uchida, 1925; *Orthopyxis platycarpa* Bale, 1914; *Sertularella* sp.; *Plumularia* sp.) are not previously known from the west coast of North America. Hydroids of *E. japonica* occurred as commensals in the mantle cavity of the mussel *Mytilus galloprovincialis* Lamarck, 1819. *Obelia griffini*, *O. gracilis* Calkins, 1899 (not its secondary homonym *Laomedea gracilis* Dana, 1846) and *O. surcularis* Calkins, 1899 are taken to be conspecific. Of the three simultaneous synonyms, precedence is assigned to the name *O. griffini* under the Principle of the First Reviser in zoological nomenclature. The species is sometimes regarded as identical with *O. dichotoma* (Linnaeus, 1758).

Key words: amphi-Pacific distributions, Anthoathecata, anthropogenic debris, invasive species, Leptothecata, northeastern Pacific, Oregon, population connectivity, transoceanic dispersal, Washington state

Introduction

The widespread geographic distribution of many hydrozoan species is often attributed to long-range dispersal by two passive mechanisms, namely shipping and transport by ocean currents (Ralph 1961). Other species of the group are believed to have been co-introduced on substrates such as commercial fisheries resources (notably oysters), aquatic plants, and organisms in aquaria (Edwards 1976; Dumont 1994). As for shipping, hydroids can be transported over great distances as part of fouling assemblages on hulls (Millard 1959; Watson 1985; Mills et al. 2007), or as hydromedusae, or polyps attached to debris, in ballast water (e.g.

Calder and Burrell 1969; Mills and Sommer 1995). Most long-distance dispersal of hydrozoan species, however, seems likely to have been accomplished over extended periods of time by rafting of sessile hydroid stages on floating natural substrates (such as seaweeds and logs) carried in ocean currents and eddies, and by attachment to wide-ranging nektonic vertebrates and even planktonic organisms such as pteropods (Cornelius 1981, 1992a, b; Jokiel 1989; Calder 1993).

Modern-day oceanic rafting has been dramatically altered by the addition of anthropogenic non-biodegradable floating materials to the open sea, thus potentially providing substrates capable of lasting far longer in the ocean than most natural

substrates. These materials, now a significant environmental menace in oceans of the world, provide rafting opportunities for hydroids (Carpenter and Smith 1972; Gregory 2009). Large anthropogenic debris resulting from natural events such as earthquakes and tsunamis, including dislodged floating docks and boats, may be significant rafting substrates as they can transport diverse and substantial benthic communities over vast distances. It has been shown that rapid, large-scale transport of suitable substrates (e.g. pumice rafting in the Pacific Ocean) fundamentally changes the dispersal range and limitations for many marine taxa, particularly those with short pelagic larval stages or where larval supply or larval behavior may be limiting factors in dispersal (Bryan et al. 2012).

We report herein on hydroids collected as part of fouling assemblages from floating derelict docks and boats carried across the Pacific Ocean from northern Japan to the west coast of the United States following the catastrophic Tōhoku earthquake and tsunami of 2011. This report follows an earlier account of a western North Pacific leptothebate hydroid (*Sertularella mutsuensis* Stechow, 1931) found on a derelict dock from Misawa, Honshu, that came ashore in June 2012 on Agate Beach, Newport, Oregon (Choong and Calder 2013). Since that report, additional material has been recovered from the substantial fouling biomass on that dock, from another dock from Misawa that washed ashore near Mosquito Creek, Olympic National Park, Washington, and from two derelict tsunami-generated boats that stranded on shores of the northwestern United States. A taxonomic account is provided of two anthoathecate and 12 leptothebate hydroid species, at least five of them not previously known from North America. Live coenosarc was observed in specimens of all 14 species.

Materials and methods

Hydroids examined here were collected from the coast of the northwestern United States on stranded debris from the Tōhoku earthquake and tsunami that struck Japan on 11 March 2011. Major substrates, collectors, and dates of collection included (1) a floating dock at Agate Beach, Newport, Oregon (coll. JW Chapman and JA Miller, 05 and 06 June 2012, Japanese Tsunami Marine Debris [JTMD] bio-fouling registry number JTMD BF-1), (2) a floating dock at Mosquito Creek, Olympic National Park, Washington (coll. JW Chapman and JA Miller, 21 December 2012,

JTMD BF-8), (3) a derelict boat in Grays Harbor, Washington (coll. J Schultz and A Pleus, 28 December 2012, JTMD BF-12), and (4) a derelict boat at Gleneden Beach, Lincoln County, Oregon (coll. JW Chapman and JA Miller, 06 February 2013, JTMD BF-23).

The two docks (JTMD-BF-1 and JTMD-BF-8) were identified as originating from the Tōhoku tsunami of 11 March 2011 based on an identification plaque and on registry numbers. These markings confirm that they were lost during the tsunami from the Port of Misawa, Aomori Prefecture, on the northeast coast of Honshu, Japan. The two skiffs or pangas (JTMD-BF-12 and JTMD-BF-23), while having lost names and numbers, were confirmed as Japanese tsunami debris by (1) their identical match to other tsunami-generated Japanese vessels that have washed ashore with registration numbers, confirming loss of the latter on 11 March 2011, (2) by maritime historical evidence that no such vessels landed prior to the tsunami on the Pacific coast of North America or Hawaii, and (3) by having species on both of them that are native to the western Pacific (including the mussel *Musculus cupreus* (Gould, 1861), the barnacle *Megabalanus rosa* (Choi, Anderson and Kim, 1992), the isopod *Ianiropsis serricaudis* (Gurjanova, 1936), the amphipod *Caprella mutica* Schurin, 1935, the nemertean *Oerstedia dorsalis* (Abildgaard, 1806), and the bryozoan *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985). While the exact origin of the two vessels is not known, they likely originated in Fukushima or Aomori Prefectures based on the identified sources of other JTMD landings in North America during 2012 and 2013 (JT Carlton, unpublished data).

Specimens, fixed and preserved in 95% ethanol, have been deposited in collections of the Invertebrate Zoology Section, Department of Natural History, Royal Ontario Museum (ROMIZ). The classification and implied relationships of hydroids adopted herein generally follows Schuchert (2012) for anthoathecates and Leclère et al. (2009) for leptothebates.

Systematic account

Order Anthoathecata Cornelius, 1992a

Family Bougainvilliidae Lütken, 1850

(?) *Bougainvillia muscus* (Allman, 1863)

(Figure 1a)

Eudendrium ramosum.—Van Beneden, 1844b: 56, pl. 4, figures 1–13 [not *Eudendrium ramosum* (Linnaeus, 1758)].

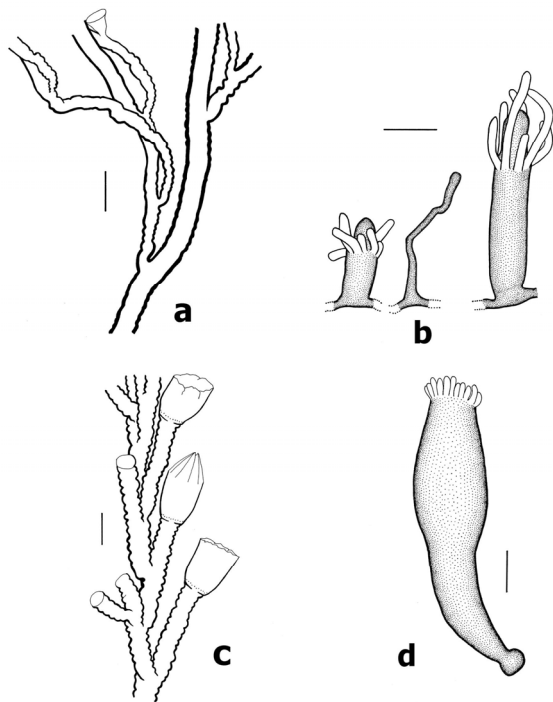


Figure 1. (a) *Bougainvillia muscus*: part of a dormant colony, with stem, branches, and a single pseudohydrotheca. ROMIZ B3986. Scale equals 0.25 mm. (b) *Stylactaria* sp.: parts of a colony, with two gastrozooids and a dactylozooid. ROMIZ B3987. Scale equals 0.25 mm. (c) *Phialella* sp.: part of a hydrocaulus, with one intact and two damaged hydrothecae. ROMIZ B3989. Scale equals 0.1 mm. (d) *Eutima japonica*: single hydranth, with basal disc. ROMIZ B3992. Scale equals 0.25 mm. Del. DR Calder.

Perigonymus muscus Allman, 1863: 12 [incorrect subsequent spelling of *Perigonimus* M. Sars, 1846].

Material.—USA: Washington state, Grays Harbor, Damon Point, on derelict boat, 28 July 2012, one dormant colony, with coenosarc but without hydranths and gonophores, coll. J Schultz and A Pleus (JTMD-BF-12), ROMIZ B3986.

Remarks.—Identification of this material as *Bougainvillia muscus* (Allman, 1863), based on overall colony morphology, is somewhat uncertain because of its poor condition. Much of the examined material comprised dead colonies growing on and amongst colonies of *Obelia longissima* (Pallas, 1766). One live colony, lacking hydranths but with coenosarc tissue in stems and branches, was present. This species, known in many earlier accounts as *Bougainvillia ramosa* (Van Beneden, 1844b), is reported to be

amphi-Pacific in distribution (Yamada 1959; Hirohito 1988; Mills et al. 2007).

Family Hydractiniidae L. Agassiz, 1862

Stylactaria sp.

(Figure 1b)

Material.—USA: Oregon, Lincoln County, Gleneden Beach, 05 February 2013, on barnacle from derelict boat, one colony, with gastrozooids and dactylozooids, gonozooids lacking, coll. JW Chapman and JA Miller (JTMD-BF-23, Sample #12), ROMIZ B3987.

Remarks.—*Stylactaria* Stechow, 1921 has been included in the synonymy of *Hydractinia* Van Beneden, 1844a in some contemporary works (e.g. Bouillon et al. 2006), while being maintained as distinct in others (e.g. Calder 2010; Miglietta et al. 2010). We follow the latter convention, and assign the colony examined here to *Stylactaria* because zooids arise from a reticulate network of perisarc-covered stolons rather than from an encrusting mat of coalesced coenosarc (see Miglietta and Cunningham 2012). In the absence of gonozooids and gonophores, the identity of the species cannot be confidently established on morphological characters. The colony was small and in good condition, and appeared to be quite young.

While the precise origin of the material is obscure, this is the first record of the genus *Stylactaria* from the west coast of the United States and Canada. It is represented by several species in Japan (Hirohito 1988; Bouillon et al. 1997), and our hydroid likely originated there.

Order Leptothecata Cornelius, 1992a

Family Phialellidae Russell, 1953

Phialella sp.

(Figure 1c)

Material.—USA: Oregon, Newport, Agate Beach, 05 June 2012, on barnacle amongst fouling from a floating dock (originating from Misawa, Honshu, Japan), one stolonial and branching colony, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, High North Dock sample), ROMIZ B3988.—USA: Oregon, Newport, Agate Beach, 05 June 2012, on barnacle amongst fouling from a floating dock (originating from Misawa, Honshu, Japan), without gonothecae, coll. JW Chapman and JA Miller, and others (from JTMD-BF-1, Samples 122–131), ROMIZ B3989.—USA: Oregon, Newport, Agate Beach, 06 June 2012, on fouling from a floating dock (originating from Misawa,

Honshu, Japan), one colony, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, High North Dock sample), ROMIZ B3990.

Remarks.—While our material could not be identified to species with confidence because of the lack of gonophores, these hydroids are likely to have originated in Japan. The floating dock from Misawa, on which specimens were found, is thought not to have acquired species in the eastern North Pacific prior to stranding. That judgment is based upon identifications of many other invertebrate and algal species, as discussed below.

A species closely resembling our material, and one reported from the Sea of Japan (Naumov 1960), is *Phialella quadrata* (Forbes, 1848). Originally described from Great Britain, it is held to be almost cosmopolitan in distribution. The specimens also closely correspond morphologically with accounts of *Opercularella rugosa* (Nutting, 1901), originally described from Harriman Alaska Expedition collections taken at Juneau, Alaska. That species has been reported as well from West Seattle, Washington, and questionably from Oakland, California (Fraser 1946). *Opercularella rugosa*, originally assigned to *Campanulina* Van Beneden, 1847 and transferred to *Opercularella* Hincks, 1868 by Cairns et al. (2002: 54), has been regarded as an indigenous west coast species. Given the similarities between *O. rugosa* and *P. quadrata*, however, studies are needed to determine whether they are identical. Both are distinguished from *O. lacerata* (Johnston, 1847) in having much stouter hydrothecae, and in having medusa stages rather than fixed sporosacs in their life cycles.

Another species from the North Pacific region with somewhat similar characters is *Campanulina chilensis* Hartlaub, 1905, reported with question from Sagami Bay, Japan, by Stechow (1913). However, our material differs from that of Stechow in having erect rather than stolonial colonies, and hydrothecae that are much less cylindrical in shape.

Family Eirenidae Haeckel, 1879

Eutima japonica Uchida, 1925

(Figures 1d, 2, 3)

Eutima japonica Uchida, 1925: 93, figure 17.

Material.—USA: Washington, Olympic National Park, near Mosquito Creek, 21 December 2012, in *Mytilus galloprovincialis* Lamarck, 1819 from floating dock (originating from Misawa, Honshu, Japan), several polyps, without gonophores, coll. JW Chapman, JA Miller, and others (JTMD-BF-8,



Figure 2. *Eutima japonica*: live polyps, in *Mytilus galloprovincialis* from dock stranded at Mosquito Creek, Washington, 21 December 2012 (JTMD-BF-8). (a) Group of hydroids on gill of host mussel. (b) Single hydroid. Photographs by Leslie Harris.

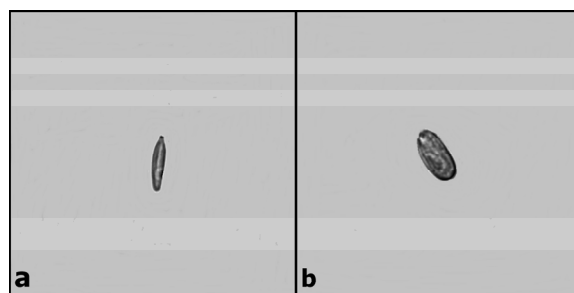


Figure 3. *Eutima japonica*: nematocysts, ROMIZ B3992. (a) Elongate microbasic mastigophore. (b) Oval microbasic mastigophore. Photomicrographs by DR Calder.

Sample #9B), ROMIZ B3991.—USA: Washington, Olympic National Park, near Mosquito Creek, 21 December 2012, in *Mytilus galloprovincialis* from floating dock (originating from Misawa, Honshu, Japan), several polyps, without gonophores, coll. JW Chapman, JA Miller, and others (JTMD-BF-8, Sample #20), ROMIZ B3992.

Remarks.—The commensal hydroid *Eutima japonica* Uchida, 1925 has been reported from cooler regions along the Japanese coast from Hokkaido in the north to Kyushu in the south, and is likely endemic to Japanese waters (Kubota 1983). The morphologically indistinguishable hydroid of *Eugymnanthea japonica* Kubota, 1979 occurs primarily in warmer waters influenced by the Kuroshio Current (Kubota 1992). According to Kubota, the two species tend to inhabit different native bivalve species, although both occur in the introduced *Mytilus galloprovincialis*. Our preliminary identification of material from tsunami debris as *E. japonica*, based on the geographic

origin of the floating dock, was confirmed by molecular analysis (Geller, unpublished data). We obtained 311 bp of Cytochrome c oxidase subunit I, which was 100% identical to GenBank accession AB458489 (Kobayashi A, Goka K, Kubota S, per Arei Kobayashi, Kyushu University, Faculty of Sciences, 6-10-1, Hakozaki, Higashi, Fukuoka 812-8581, Japan, unpublished), identified as *Eutima japonica* and collected in Japan. Sequences for the genetically distinct *Eugymnanthea japonica* have also been characterized (Govindarajan et al. 2005b).

Although the exact relationship with their hosts is not clear, polyps of *Eutima japonica* live in the mantle cavities of bivalve molluscs, attaching to tissues of the mantle cavity by stolonal structures or by hydrorhizae penetrating into the host tissues (Boero and Bouillon 2005).

Commensal eutimid hydroids are previously unreported from the west coast of North America, and the species reported here is considered alien to North American waters. Related species occurring in the western North Atlantic include *Eutima ostrearum* Mattox and Crowell, 1951 (from the Mangrove Cupped Oyster, *Crassostrea rhizophorae*) in Puerto Rico, and *Eutima* sp. from Atlantic (Kubota and Larson 1990) and Gulf coasts (Tolley et al. 2010) of Florida (in both regions in the Eastern Oyster, *Crassostrea virginica*).

Family Campanulariidae Johnston, 1837

Obelia griffini Calkins, 1899

(Figures 4a–c)

Obelia griffini Calkins, 1899: 357, pl. 4, figures 18, 18A–C; pl. 6, figure 18D.

Material.—USA: Oregon, Lincoln County, Gleneden Beach, 05 February 2013, on *Lepas* sp. from derelict boat, one colony, with gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-23), ROMIZ B3995. —USA: Oregon, Lincoln County, Gleneden Beach, 05 February 2013, on styrofoam from stranded boat, one colony, with gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-23, un-numbered sample), ROMIZ B3996. —USA: Oregon, Newport, Agate Beach, 06 June 2012, amongst fouling from a floating dock (originating from Misawa, Honshu, Japan), one colony, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, High North Dock sample), ROMIZ B3997. —USA: Oregon, Newport, Agate Beach, 05 June 2012, amongst fouling from a floating dock (from Misawa, Honshu, Japan), one colony, with gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1,

Sample B12), ROMIZ B3998. —USA: Oregon, Newport, Agate Beach, 05 June 2012, on barnacles and amongst fouling from a floating dock (originating from Misawa, Honshu, Japan), without gonothecae, coll. JW Chapman, JA Miller, and others (JTMD-BF-1, Samples 122–131), ROMIZ B3999. —USA: Washington, Olympic National Park, near Mosquito Creek, 21 December 2012, from fouling on floating dock (originating from Misawa, Honshu, Japan), several colonies, without gonothecae, coll. JW Chapman, JA Miller, and others (JTMD-BF-8, Sample #20), ROMIZ B4000. —USA: Washington, Olympic National Park, near Mosquito Creek, 21 December 2012, from fouling on floating dock (from Misawa, Honshu, Japan), several colonies, with gonothecae, coll. JW Chapman, JA Miller, and others (JTMD-BF-8, Sample #34), ROMIZ B4001.

Remarks.—Hydroid colonies examined here corresponded most closely with accounts of *Obelia griffini* Calkins, 1899 (type locality: Puget Sound, Washington), generally considered conspecific with *O. dichotoma* (Linnaeus, 1758). We retained *O. griffini* as distinct largely because hydrothecae in our specimens were round rather than polygonal in cross-section as in *O. dichotoma*, and hydrothecal margins were entire rather than polyhedral. According to Fraser (1914), *O. griffini* is also more profusely branched than *O. dichotoma*. Moreover, it seems likely that the supposedly cosmopolitan *O. dichotoma* (type locality: SW coast of England) comprises a species complex, like its congener *O. geniculata* (Linnaeus, 1758) (Govindarajan et al. 2005a).

Similar and regarded as conspecific with *Obelia griffini* are *O. surcularis* Calkins, 1899 and *O. gracilis* Calkins, 1899, both originally described from Puget Sound, Washington (type locality: Scow Bay, Port Townsend Harbor). Characters used to distinguish the three are believed by us to have been based merely on different growth forms. Of the three simultaneous synonyms *O. griffini*, *O. gracilis*, and *O. surcularis*, we assign precedence to the name *O. griffini* under the Principle of the First Reviser (ICZN Art. 24.2). In addition, *Obelia gracilis* Calkins, 1899 is a junior secondary homonym of *Lomedea* (sic) *gracilis* Dana, 1846 from gulfweed in the Sargasso Sea (34°39'N, 72°01'W). A replacement name for *O. gracilis* Calkins is unnecessary as it is now a junior synonym of *O. griffini* (ICZN Art 60.2).

Hydroids identified as *Obelia griffini* or one of its synonyms have been reported from Puget

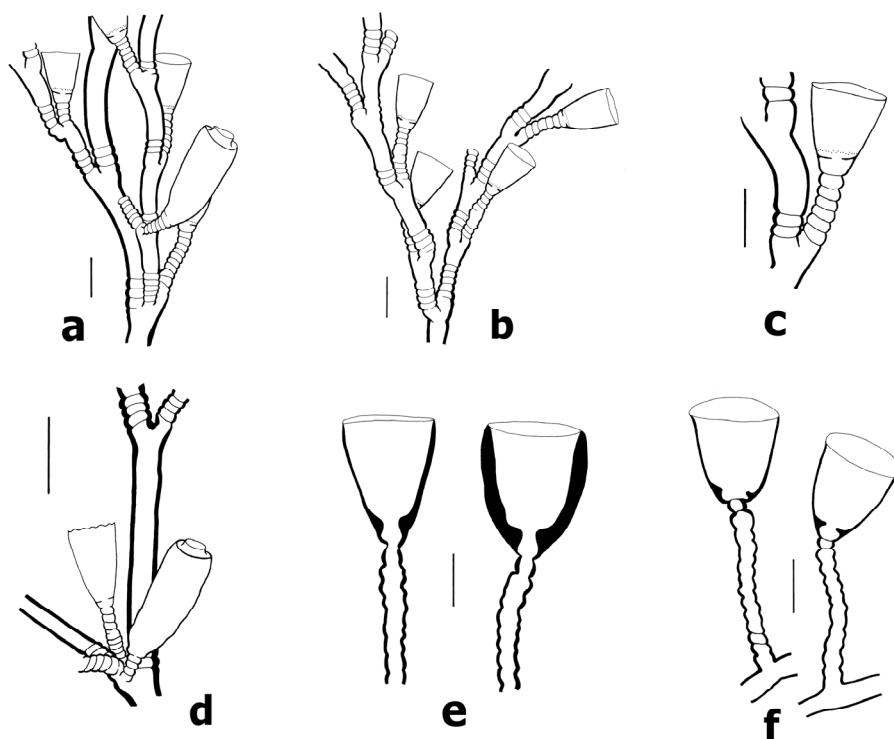


Figure 4. (a) *Obelia griffini*: part of a colony, with hydrothecae and a gonotheca. ROMIZ B3996. Scale equals 0.25 mm. (b) *Obelia griffini*: part of a colony, with four hydrothecae. ROMIZ B3999. Scale equals 0.25 mm. (c) *Obelia griffini*: part of a colony, with a single hydrotheca. ROMIZ B3996. Scale equals 0.2 mm. (d) *Obelia longissima*: part of a colony, with a hydrotheca and a gonotheca. ROMIZ B4002. Scale equals 0.5 mm. (e) *Orthopyxis caliculata*: two views of a single bilaterally symmetrical hydrotheca, showing differential thickening of perisarc. ROMIZ B3993. Scale equals 0.25 mm. (f) *Orthopyxis platycarpa*: two hydrothecae. ROMIZ B3994. Scale equals 0.2 mm. Del. DR Calder.

Sound northwards to several localities around Vancouver Island (Fraser 1946). *Obelia gracilis* Calkins (not *O. gracilis* Dana) has also been reported from China (Hargitt 1927; Ling 1938; Gao 1956; Wei 1959), and it was characterized as one of the hydroid species typical of the South Kurilean region of Russia by Antsulevich (1992).

Obelia griffini was found on three of the four stranded objects sampled as part of this study. The history of the species is not well-known across the North Pacific. Given its propensity to be a fouling organism, we regard it as cryptogenic on the coasts of both eastern Asia and western North America.

***Obelia longissima* (Pallas, 1766)**

(Figure 4d)

Sertularia longissima Pallas, 1766: 119.

Material.—USA: Washington state, Grays Harbor, Damon Point, on derelict boat, 28 December 2012,

several colonies, with empty gonothecae, coll. J Schultz and A Pleus (JTMD-BF-12), ROMIZ B4002.

Remarks.—*Obelia longissima* (Pallas, 1766) is amphi-Pacific in distribution, having been reported from the Bering Sea (Naumov 1960) southwards to Korea (Park 1990) and the north coast of China (Gao 1956; Wei 1959) in the west, and from Alaska to California in the east (Fraser 1937, 1946; Calder 1970). It occurs on both sides of the North Atlantic Ocean as well, and populations extend into Arctic waters (Naumov 1960; Calder 1970, 2012; Schuchert 2001).

Although colonies of *Obelia longissima* are known to survive for at least several months (Cornelius 1990), the life span of a given genet is potentially much longer. Hydroids that clone by asexual reproduction (as is the case with *O. longissima*) may survive for very long periods, according to Gili and Hughes (1995: 374, 375). Moreover, resting stages (menonts) exist in hydroids

that prolong survival (Calder 1990). Given the large size (up to 24 cm high), weathered condition, and empty gonothecae of colonies examined here, we conclude that they had been on the derelict boat for at least several months and that the colonies or their genetically identical predecessors originated in Japan.

***Orthopyxis caliculata* (Hincks, 1853)**

(Figure 4e)

Campanularia caliculata Hincks, 1853: 178, pl. 5, figure B.

Material.—USA: Washington, Olympic National Park, near Mosquito Creek, 21 December 2012, one small colony, from a floating dock (originating from Misawa, Honshu, Japan), without gonophores, coll. JW Chapman, JA Miller, and others (JTMD-BF-8, Sample #M3), ROMIZ B3993.

Remarks.—Material examined here corresponds in morphology to hydroids sometimes known as *Orthopyxis caliculata* (Hincks, 1853), originally described from the British Isles. The species is frequently held to be identical with *Orthopyxis integra* Macgillivray, 1842 (e.g., Levinsen 1893; Broch 1910, 1918; Kramp 1911; Naumov 1960; Cornelius 1982, 1995; Vervoort and Watson 2003; Schuchert 2013b). Broch (1918: 160) reported finding forms corresponding to the two putative species, together with transitional ones, on the same stolons. Nevertheless, molecular studies are warranted to establish the relationship between *O. integra* and *O. caliculata* because the two appear to differ in characters of both trophosome and gonosome. Notably, hydrothecae are bilaterally symmetrical in *O. caliculata* rather than being radially symmetrical as in *O. integra* (Table 1), and gonothecae are sac-shaped without annulated walls instead of being nearly cylindrical with spirally grooved walls (Naumov 1960). Despite the absence of gonothecae in our sample, differences in hydrothecal morphology sufficiently differentiate *O. caliculata* from *O. integra* (Table 1). As for *O. integra*, widely reported and generally believed to be nearly cosmopolitan (Cornelius 1995), its identity is not at all firmly established. The original account of the species was brief and no illustration was provided. Type material, from the mouth of the River Don at Aberdeen, Scotland, could not be located in a study of eastern North Atlantic campanulariids by Cornelius (1982). A neotype is needed to objectively define the species.

Hirohito (1995) provided taxonomic information on several species of *Orthopyxis* L. Agassiz,

1862 from Japan, although all of them were referred by him to genus *Campanularia* Lamarck, 1816. *Campanularia caliculata* was treated by him as a valid species, and the account of his material from Japan corresponds with hydroids examined here. Hirohito's specimens were similar to ones that he had examined from the Shetland Islands, UK, in collections at the British Museum (Natural History) (now The Natural History Museum) in London. In the western North Pacific, *O. caliculata* has also been reported from Korea (Park 1990) and Sakhalin, Russia (Hirohito 1995).

Hydroids corresponding to accounts of *Orthopyxis caliculata* have been reported earlier from the west coast of North America by Nutting (1901, 1915). Notably, however, those identified by Calkins (1899) as *O. caliculata* from Puget Sound, Washington, differ somewhat in morphology, and Stechow (1919) provided a new name, *O. pacifica*, for them. Fraser (1914, 1937, 1946), who seems to have followed Calkins' concept of the species, assigned it to *Eucopeella* von Lendenfeld, 1883. The identity of *Campanularia compressa* Clark, 1877 from Alaska, resembling *O. caliculata* but included in the synonymy of *O. integra* by Schuchert (2013b), needs to be clarified.

***Orthopyxis platycarpa* Bale, 1914**

(Figure 4f)

Orthopyxis platycarpa Bale, 1914: 79, pl. 11, figure 3, pl. 12, figure 3.

Material.—USA: Oregon, Lincoln County, Gleneden Beach, 05 February 2013, from derelict boat, several pedicels with hydrothecae, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-23), ROMIZ B3994.

Remarks.—These hydroids correspond with accounts of *Orthopyxis platycarpa* Bale, 1914 from Japan (Stechow and Uchida 1931; Hirohito 1995), China (Ling 1938), and Russia (Naumov 1960; Antsulevich 1987). Specimens from Korea identified as this species by Rho (1967) more closely resemble *O. caliculata* in our opinion. *Orthopyxis platycarpa* has been regarded in some works (e.g. Schuchert 2013b) as conspecific with *O. integra* (Macgillivray, 1842), although gonothecae of the latter usually have a distinctive spiral carina around the exterior wall instead of being smooth. Other apparent differences distinguishing *O. platycarpa* from *O. integra* include the frequent occurrence of a convex submarginal band of thickened perisarc on the hydrothecae, and gonothecae that are distinctly flattened (Bale 1914). Moreover, acrocysts are extruded from female

Table 1. Comparisons of some trophosomal characters in specimens of *Orthopyxis caliculata*, *O. platycarpa*, and *O. integra* from collections at the Royal Ontario Museum, together information on *O. platycarpa* from Naumov (1960, as *Campanularia platycarpa*).

| Measurements (μm): | <i>O. caliculata</i> (ROMIZ B3993) | <i>O. platycarpa</i> (ROMIZ B3994) | <i>O. platycarpa</i> (Naumov 1960) | <i>O. integra</i> (ROMIZ B4020) |
|---|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|
| Hydrotheca height (A) | 1160–1190 | 680 | 320–640 | 1170–1800 |
| Hydrotheca maximum width (B) | 800–830 | 550 | not stated | 1020–1210 |
| Hydrotheca mouth maximum diameter (C) | 800–860 | 570 | 270–400 | 940–1210 |
| Hydrothecal submarginal perisarc thickening (D) | 50–80 | 10 | not stated | 90–121 |
| Pedicel height (E) | 1193–2260 | 1130 | 800–4000 | 5070–9160 |
| Hydrothecal symmetry | bilateral | radial | radial | radial |
| Hydrothecal submarginal band | no | yes | yes | no |

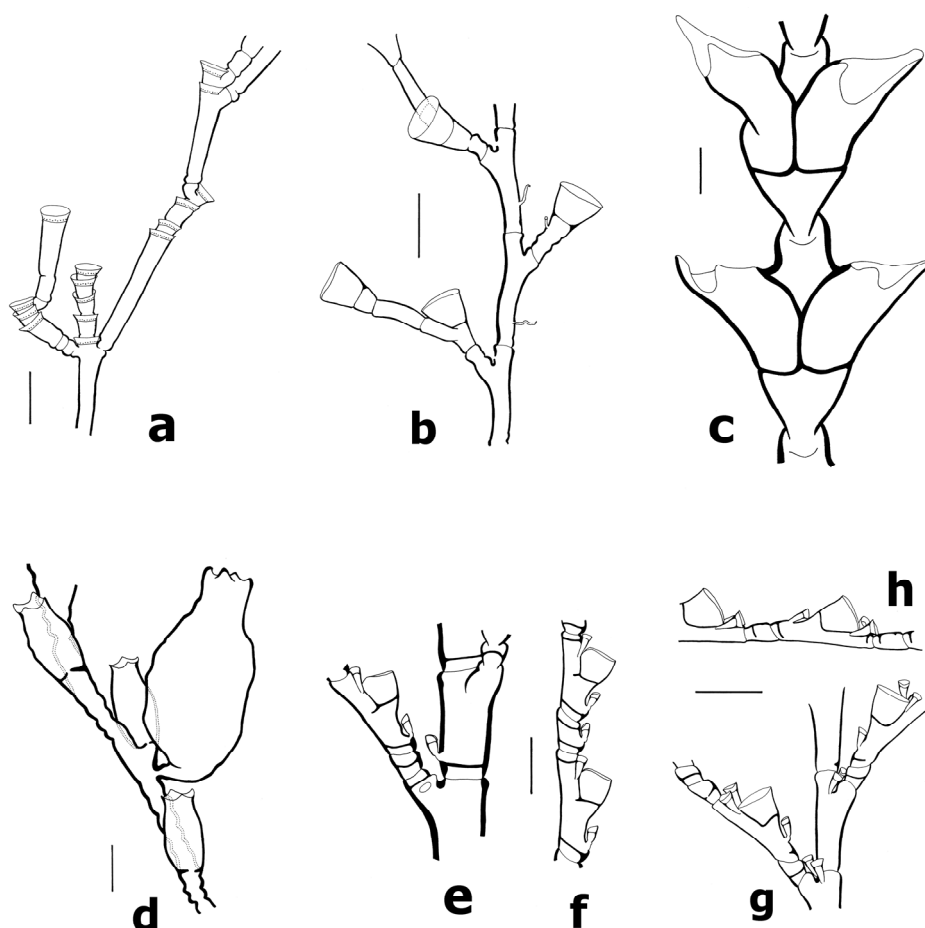


Figure 5. (a) *Halecium tenellum*: part of a colony, with hydrothecae. ROMIZ B4004. Scale equals 0.25 mm. (b) *Hydrodendron gracile*: part of a colony, with four hydrothecae and three nematophores. ROMIZ B4005. Scale equals 0.2 mm. (c) *Amphisbetia furcata*: part of a hydrocaulus, with two pairs of hydrothecae. ROMIZ B4008. Scale equals 0.1 mm. (d) *Sertularella* sp.: part of a hydrocaulus, with three hydrothecae and a gonotheca. ROMIZ B4009. Scale equals 0.25 mm. (e) *Plumularia* sp.: part of a hydrocaulus, and basal segments of a hydrocladium. ROMIZ B4006. Scale equals 0.25 mm. (f) *Plumularia* sp.: part of a hydrocladium, with nematothecae and two hydrothecae. ROMIZ B4006. Scale equals 0.25 mm. (g) *Plumularia setacea*: part of a hydrocaulus, and basal segments of two hydrocladia. ROMIZ B4007. Scale equals 0.25 mm. (h) *Plumularia setacea*: part of a hydrocladium, with nematothecae and two hydrothecae. ROMIZ B4007. Scale equals 0.25 mm. Del. DR Calder.

gonophores of *O. platycarpa* rather than eumedusoids, as in *O. integra* (Hirohito (1995). Considerable differences in hydrothecal dimensions were apparent in specimens of *O. platycarpa*, *O. integra*, and *O. caliculata* examined here (Table 1).

This species has not been reported before from the west coast of North America.

Family Haleciidae Hincks, 1868

Halecium tenellum Hincks, 1861

(Figure 5a)

Halecium tenellum Hincks, 1861: 252, pl. 6, figures 1–4.

Material.—USA: Oregon, Newport, Agate Beach, 05 June 2012, on barnacle fragment amongst fouling from a floating dock (originating from Misawa, Honshu, Japan), one colony, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, High North Dock sample), ROMIZ B4003.—USA: Washington, Olympic National Park, near Mosquito Creek, 21 December 2012, on barnacle from fouling on floating dock (originating from Misawa, Honshu, Japan), without gonothecae, coll. JW Chapman, JA Miller, and others (JTMD-BF-8, Sample #9B), ROMIZ B4004.

Remarks.—Identification of examined material is somewhat uncertain because of the lack of gonophores, although the trophosomes corresponded most closely with accounts of *Halecium tenellum* Hincks, 1861. Our material showed occasional annulation in the stems (Fraser 1937), and weak constrictions were generally present at the base of the branches as reported by Hirohito (1995). *Halecium tenellum* is known from both northeastern and northwestern Pacific regions, having been reported in the latter area from Japan (Jäderholm 1919; Yamada 1959; Hirohito, 1995), Russia (Naumov 1960; Antsulevich 1987), Korea (Park 1991), and with some question from China (Hargitt 1927). Records from the northeastern Pacific are summarized in Fraser (1937). *Halecium tenellum* has been very widely reported (from Atlantic, Pacific, Indian, and Arctic oceans), and genetic studies may reveal the existence of a species complex.

Hydrodendron gracile (Fraser, 1914)

(Figure 5b)

Ophiodes gracilis Fraser, 1914: 171, pl. 22, figures 82A–D.

Material.—USA: Oregon, Lincoln County, Gleneden Beach, 05 February 2013, from derelict boat, one colony, without gonothecae, coll. JW

Chapman and JA Miller (JTMD-BF-23), ROMIZ B4005.

Remarks.—Fraser (1914) described this hydroid, as *Ophiodes gracilis*, from Vancouver Island and the Queen Charlotte Islands (=Haida Gwaii), British Columbia. *Plumularia linkoi* Naumov, 1960, originally described from the Black Sea, has been regarded as a probable synonym (Schuchert 2013b). In the North Pacific Ocean, *Hydrodendron gracile* has been reported from the Sea of Japan and the Kurile Islands (Naumov 1960, as *Plumularia magellanica moneroni* Naumov, 1960; Antsulevich 1987, as *Hydrodendron gracilis*) as well as from British Columbia (Fraser 1937, as *Ophiidissa gracilis*). The colony examined here, in quite good condition and appearing relatively young, closely resembles accounts of the species by Naumov (1960) and Antsulevich (1987). A combination of characters (stolonial colony form; monosiphonic hydrocaulus; tiny, curved nematothecae) distinguish the species from others of the genus known from the northern North Pacific (Fraser 1937; Hirohito 1995). *Hydrodendron gracile* was originally described from sterile material, and it remains an inadequately characterized species.

Family Sertulariidae Lamouroux, 1812

Amphisbetia furcata (Trask, 1857)

(Figure 5c)

Sertularia furcata Trask, 1857: 101, pl. 5, figures 2a–e.

Material.—USA: Oregon, Newport, Agate Beach, 05 June 2012, wash from fouling from a floating dock (originating from Misawa, Honshu, Japan), fragment of a single stem, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, Sample B12), ROMIZ B4008.

Remarks.—*Amphisbetia furcata* (Trask, 1857), originally described from San Francisco Bay, California, and *A. pacifica* Stechow, 1931, type locality Mutsu Bay, Japan, differ only in minor characters. According to Yamada (1959: 69), *A. pacifica* is distinguished in having “...2 distinct spiral constrictions at the base of the stem and in gonothecae which are not globular but elongated oval and having unremarkable shoulders.” We consider such differences to be taxonomically insignificant and agree with Antsulevich (1987) that the two are coterminous. Notably, gonothecae of *A. furcata* are known to vary in shape (see Clark 1876, pl. 39, fig. 3). Moreover, diagrams of gonothecae of *A. furcata* from California by Torrey (1902) and of *A. pacifica* from Japan by Hirohito (1995) are much alike. The bases in

both putative species have hinge joints, frequent in sertulariid species occurring on algal substrates that are swept by waves and currents.

Amphisbetia furcata or its synonym *A. pacifica* have been reported from shores along both the northeastern and northwestern Pacific (e.g. Fraser 1937, 1946; Gao 1956; Yamada 1959; Wei 1959; Rho 1967; Antsulevich 1983, 1987; Park 1990; Hirohito 1995). Coenosarc was still apparent within the perisarc skeleton of our fragmentary hydroid, but it was old, almost completely covered in diatoms, and in quite poor condition. We therefore conclude that it originated in Japan.

***Sertularella* sp.**

(Figure 5d)

Material.—USA: Oregon, Newport, Agate Beach, 05 June 2012, from fouling on a floating dock (originating from Misawa, Honshu, Japan), several colony fragments, with gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, Sample B12), ROMIZ B4009.—USA: Oregon, Newport, Agate Beach, 05 June 2012, from fouling on a floating dock (originating from Misawa, Honshu, Japan), one fragment, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, Sample B19), ROMIZ B4010.

Remarks.—Comparison of our samples to documented Japanese and northwestern Pacific species of *Sertularella*, such as *S. levigata* Stechow, 1931, *S. miurensis* Stechow, 1921 (including *S. miurensis* var. *pungens* Stechow, 1931), *S. lagenoides* Stechow, 1919, *S. mutsuensis* Stechow, 1931, and *S. sagamina* Stechow, 1921, as well as northeastern Pacific and North Atlantic congeners, shows that material above appears morphologically distinct. Several species assigned to *Sertularella* Gray, 1848 in the North Pacific region, including the species listed above, are inadequately described and poorly differentiated, and a taxonomic reassessment of them is needed. As a result, we have yet to refer our material with confidence to any of these putative species. Hydroids in our samples (ROMIZ B4009, ROMIZ B4010) do not readily correspond with species of *Sertularella* from the west coast of North America that we know. Pending further taxonomic analysis and identification, we surmise that this species is likely alien to North America. Given the uncertain identity of this hydroid, a preliminary description of it is given below.

Observed thickening of the perisarc throughout the exoskeleton and annulations on internodes below the hydranths are both consistent with

morphological adaptations to potentially damaging moving-water conditions. Annulations allow the hydrocaulus to bend without damage, and enable orientation that enhances food capture in strong currents (Hughes 1992).

Description.—Colony erect, unbranched, with a monosiphonic, somewhat geniculate hydrocaulus comprised of a succession of short, pedicel-like internodes having 2–4 annulations basally; each such internode slender basally, thickest distally at insertion of hydrotheca. Perisarc thickened throughout. Hydrothecae flask-shaped, arranged alternately to somewhat spirally; walls appearing mostly smooth in lateral view but with 2–3 slight annulations apparent in polar view, constricted below margin, with up to half of adcauline wall adnate to internode; margin slightly flaring, with four distinct, equally-developed cusps; operculum of four triangular valves; hydrothecal perisarc variably thickened internally below aperture, in some cases appearing bulbous and resembling intrathecal cusps; true intrathecal cusps absent or not apparent in polar view. Gonothecae sac-shaped with a narrow neck, each arising by a short, tapered pedicel from internode below base of hydrotheca, walls appearing almost smooth laterally but with faint rings visible in polar view; aperture surrounded by 4–5 cusps; internal projections absent.

Family Plumulariidae McCrady, 1859

***Plumularia* sp.**

(Figures 5e, f)

Material.—USA: Oregon, Newport, Agate Beach, 05 June 2012, on fouling from a floating dock (from Misawa, Honshu, Japan), one colony, with remnants of coenosarc in stems, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-1, Sample B12), ROMIZ B4006.

Remarks.—This hydroid was represented by a single colony fragment that was sterile and in imperfect condition. In many respects it corresponds in morphology with accounts of *Plumularia lagenifera* Allman, 1885, a species distinguished from the related *P. setacea* (Linnaeus, 1758) in having hydrothecae with a convex abcauline wall (Schuchert 2013a) (compare Figures 17, 18). However, *P. lagenifera* shares that character with *P. caliculata* Bale, 1888 from Australia and Japan. The two species are most easily distinguished by their female gonothecae, which were absent in our material. Those of *P. caliculata* are globular rather than flask-shaped with a tubular neck, and a marsupium is extruded. Our specimen was

compared to a sample of *P. lagenifera* from the Vancouver Island area in collections at the Royal Ontario Museum (Canada, British Columbia, Stuart Channel, Round Island, depth 37 m, 15 June 1923, ROMIZ B4011). No morphological differences were apparent between them. Lengths of some trophosomal characters were closer to those of *P. lagenifera* than to *P. caliculata* (Table 2). We conclude that the specimen can be confidently identified only to generic rank in the absence of gonophores, but its substrate and collection date point to *P. caliculata* (see Discussion). Although the colony fragment was in rather poor condition, strands of coenosarc were still visible within the perisarc skeleton.

Plumularia lagenifera, originally described from Vancouver Island, British Columbia (Allman 1885), is a familiar species along the west coast of the United States and Canada (Fraser 1937; Mills et al. 2007). Although it has been reported in the western North Pacific (Stechow 1913; Hargitt 1927), those records are now believed to have been based on hydroids of *P. caliculata* (Stechow 1923: 17; Yamada 1959: 79; Hirohito 1995: 271). Rho and Park (1980) reported *P. lagenifera* from Korea, but their hydroid seems likely to have been *P. caliculata* as well.

***Plumularia setacea* (Linnaeus, 1758)**

(Figures 5g, h)

Sertularia setacea Linnaeus, 1758: 813.

Material.—USA: Oregon, Lincoln County, Gleneden Beach, 05 February 2013, from derelict boat, several plumes, without gonothecae, coll. JW Chapman and JA Miller (JTMD-BF-23), ROMIZ B4007.

Remarks.—We assigned our material to *Plumularia setacea* (Linnaeus, 1758) in spite of the total absence of nematothecae on ahydrothecate internodes of the hydrocladia. Apart from axillary ones at apophysal bases, nematothecae were also absent on internodes of the hydrocaulus. Trophosomes thus resembled hydroids identified as *Plumularia* sp. by Hirohito (1995) from Sagami Bay, Japan, although his specimens were illustrated without internal perisarc ridges. The ahydrothecate internodes of our specimens were consistently very short and they were often replicated, with as many as six occurring in sequence. In other respects, hydroids examined here generally corresponded to accounts of *P. setacea*, including that of Schuchert (2013a). While we provisionally conclude that the observed differences in morphology are not taxonomically

significant, we acknowledge that a high degree of genetic diversity exists within *P. setacea*, and cryptic species may exist (Schuchert 2014).

Plumularia setacea is taken to be an amphipacific species (e.g. Jäderholm 1896; Fraser 1937; Gao 1956; Wei 1959; Naumov 1960; Rho 1967; Hirohito 1995; Schuchert 2013a). Colonies appear to have been present on the derelict boat for several weeks or months; parts of some plumes comprised only empty skeletal perisarc, and bases of hydrocauli were overgrown with bryozoans.

Discussion

Of more than 100 species found on the dock from Misawa, Japan (JTMD-BF-1), that landed in Oregon during June 2012, and more than 30 species on the Japanese vessel that washed ashore at Gleneden, Oregon, during February 2013 (JTMD-BF-23) (JT Carlton, JW Chapman, J Geller, JA Miller, and G. Ruiz, unpublished data), none appear to have been acquired after the vessel entered the eastern Pacific Ocean. It is thus difficult to imagine that only species of eastern Pacific hydrozoans settled on these objects but no other eastern Pacific marine invertebrates. In contrast, the second dock from Misawa that washed ashore during December 2012 in the state of Washington (JTMD-BF-8) included eastern Pacific species of snails, isopods, and ascidians, among other possible taxa, acquired as the dock floated along the North American coast before or after landing.

None of the hydroids discussed here are clearly introduced (Table 3) on the Pacific coast of North America, but several species may be cryptogenic - that is, we do not know whether they are native or exotic. These include *Bougainvillia muscus*, *Obelia griffini*, and *Obelia longissima*. Authors have previously considered the first and last as possible introductions to the eastern Pacific Ocean, based upon their history, patchy distribution, and/or predominance in ports and harbors (Mills et al. 2007). In all, six species found on Japanese tsunami marine debris are not yet known from the eastern Pacific (Table 3): *Stylactaria* sp., *Eutima japonica*, *Orthopyxis platycarpa*, *Sertularella* sp., *S. mutsuensis*, and *Plumularia* sp. All of these species should be included as target taxa in biodiversity surveys of fouling communities on the Pacific coast of North America. Especially to be sought for there would be evidence of *Eutima japonica* in species of *Mytilus*, or indeed, in other bivalves (see Kubota 1983; Baba et al. 2007).

Table 2. Size comparisons of some characters in *Plumularia lagenifera*, *Plumularia caliculata*, and *Plumularia* sp.

| Length (μm) | <i>Plumularia lagenifera</i> (in Schuchert 2013) | <i>Plumularia</i> sp. (ROMIZ B4006) | <i>Plumularia caliculata</i> (in Vervoort and Watson 2003) |
|----------------------------|---|--|--|
| Stem internode | 405–589 | 455–485 | 310–390 |
| Branch, thecate internode | 395–514 | 325–410 | 265–335 |
| Branch, athecate internode | 153–226 | 140–195 | 100–115 |
| Hydrotheca, abcauline wall | 90–115 | 105–125 | 45–73 |

Table 3. The North Pacific distributions and biogeographic origins of hydroids associated with Japanese Tsunami Marine Debris (JTMD) coming ashore on the Pacific coast of North America. Data on *Sertularella mutsuensis* from Choong and Calder (2013).

| Species | Previously known from the North Western Pacific (NWP) | Previously known from the North Eastern Pacific (NEP) | Status in NEP: N native I introduced C cryptogenic | Comments |
|---------------------------------|--|--|--|--|
| <i>Bougainvillia muscus</i> (?) | + | + | I? (Mills et al. 2007: 151, "probably introduced") | Identification uncertain due to poor condition of material. Amphi-Pacific |
| <i>Stylactaria</i> sp. | ? | - | Not known from NEP | Genus represented in NWP |
| <i>Phialella</i> sp. | ? | ? | | Dock not regarded as having acquired species from NEP (see text). Amphi-Pacific (?) |
| <i>Eutima japonica</i> | + | - | Not known from NEP | |
| <i>Obelia griffini</i> | +(see Comments) | + | C (so designated here) | While known from China and Russia, this appears to be the first record from Japan, based upon JTMD-BF-1 and BF-23 samples (not JTMD-BF-8, which is regarded as having acquired Eastern Pacific taxa; see text discussion). Amphi-Pacific |
| <i>Obelia longissima</i> | + | + | C? (so designated here; Mills et al. 2007: 164; "probable ship fouling introductions") | Amphi-Pacific |
| <i>Orthopyxis caliculata</i> | + | + | N | Amphi-Pacific |
| <i>Orthopyxis platycarpa</i> | + | - | Not known from NEP | |
| <i>Halecium tenellum</i> | + | + | N (see Comments) | Reported to have a broad temperate-tropical range in the Atlantic, Pacific, Indian, and Arctic oceans, and may be a species complex. Amphi-Pacific |
| <i>Hydrodendron gracile</i> | + | + | N | First record for Japan; vessel not regarded as having acquired species from NEP (see text). Amphi-Pacific |
| <i>Amphisbetia furcata</i> | + | + | N | |
| <i>Sertularella mutsuensis</i> | + | - | Not known from NEP | Reported earlier by Choong and Calder (2013) |
| <i>Sertularella</i> sp. | ? | ? | Not known from NEP | See text discussion; JTMD-BF-1 is not regarded as having acquired species from NEP (see text) |
| <i>Plumularia</i> sp. | ? | - | - | Dock not regarded as having acquired species from NEP (see text); possibly new to NEP |
| <i>Plumularia setacea</i> | + | + | N | Amphi-Pacific |

Worldwide distribution of many hydroid genera and species gives the impression of near-cosmopolitanism; therefore, continuing refinement of species-level taxonomy in making comparisons between different areas of the world is needed (Cornelius 1992b). Our examination of hydroids on tsunami debris, including species of *Orthopyxis*, *Obelia*, *Sertularella*, and *Plumularia* underscores this imperative and provides additional data on hydroids that form a potential “species club” of rafters. Although rafting hydroids, especially leptothecates, tend to be substrate generalists (Cornelius 1992b), unusually large anthropogenic floating debris such as docks and boats may effectively disperse even commensal species such as *Eutima japonica* by functioning as substrata for their hosts. Our results confirm that tsunami debris can dramatically influence connectivity of marine communities.

Acknowledgements

Gratitude is extended to A Pleus and J Schultz, Washington Department of Fish and Wildlife, for providing samples from the derelict boat that stranded at Grays Harbor, Washington. We are indebted to T Murphy for assisting with field collections and laboratory processing of samples, to D Carlton for help in sorting samples, and to X Song of Qingdao, China, for providing PDF copies of several relevant publications on hydroids of China. The photographs of *Eutima japonica* in Figure 2 were taken by L Harris. Thanks are due to M Zubowski, Royal Ontario Museum, for providing collections management assistance, and to A Antsulevich and two anonymous referees for constructive reviews of the manuscript. JT Carlton, JW Chapman, and JA Miller gratefully acknowledge the support of the Oregon Sea Grant Program (Grant #R/NIS-23-PD), and Carlton, Chapman, Miller, and Jonathan Geller the support of the National Science Foundation (Grants #1266417 (Carlton), 1266397 (Miller/Chapman) and 1266234 (Geller)).

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