

**A post-voyage analysis of hull biofouling on the vessels
POINT LOMA and FLORENCE after transit from
California to Texas**

Final Report

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Executive Summary

A post-transit survey and analysis of biofouling on the National Defense Reserve Fleet (NDRF) vessels POINT LOMA and FLORENCE was carried out in Brownsville, TX after a similar survey was conducted prior to their departure from Suisun Bay, California. The vessels were moved per the U. S. Maritime Administration's (MARAD) mandate to dispose of its obsolete vessels. The biofouling attached to the underwater surfaces of these ships is a possible source of non-native species, and we conducted this pilot study to characterize the pre- and post-transit biofouling communities on the vessels. The surveys were carried out using the same standardized protocols used during the Suisun Bay surveys with 92 samples and 99 photo-quadrats taken across both ships.

The ships experienced shipside water temperatures ranging from 9.8°C to 31.5°C and salinity ranges from 0-37 ppt during the 43+ day tow. There was a significant difference in biofouling assemblage organization between pre- and post- transit surveys. Much of the 3-dimensional vertical growth of fouling was reduced, however, there was a higher number of species recorded on the vessels in Brownsville (57) compared to the surveys in Suisun Bay (22). This reduction in biomass from the pre-transit survey, particularly of the dominant species *Conopeum osburni*, was not reflected in the presence/absence analysis of biological samples where *C. osburni* was found in 98% of samples collected across both vessels. Numerous species were found on the hulls during the post-transit survey but were absent from the pre-transit survey. These species may have attached to the hull during the transit or in the destination region; some may have been present as small dormant stages in Suisun Bay or, for rare species found in fewer than 5% of samples, may simply have not been encountered during sampling in Suisun Bay.

Of the species that were recorded on the hulls in Texas, at least seven are non-native to the western Gulf of Mexico, and two of these are known to be already established there. The Asian clam, *Corbula amurensis*, which has a history of invasion that has led to significant changes in the benthic community and food web structure in San Francisco Bay, was not found (alive) on the vessels upon arrival in Texas.

Overall, the expected reduction in organism biomass was observed, and we attribute this to the effect of the voyage from California to Texas. However, 57 species were present on the hulls and we collected live specimens of many of these, suggesting that species and population level bioinvasions could occur. Determining the level of risk associated with obsolete vessel movements requires further studies of: 1) spatial and temporal variation at source regions, 2) more replicate assessments of pre- and post-transit events and 3) determinations of organism viability at recipient regions.

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INTRODUCTION

Purpose

The vessels POINT LOMA and FLORENCE were transferred from the Suisun Bay Reserve Fleet (San Francisco Bay, California) to Brownsville, Texas where they were to be dismantled. In an effort to learn more about the biofouling attached to the underwater surfaces of these ships and the potential for biological invasions to result from their transfer, we conducted pre- and post- voyage biological surveys. The results of the pre-transit survey are provided in a report entitled “Hull Biofouling on the vessels POINT LOMA and FLORENCE in the Reserve Fleet at Suisun Bay, Ca: A pilot study with respect to potential transfer of non-native species” (Davidson et al., 2006). Details regarding the hull fouling vector, the history and characteristics of both vessels, Suisun Bay and the pre-transit biofouling communities can be found in that report. This report presents the analysis of biofouling data collected on both vessels soon after they arrived in the Port of Brownsville, Texas, with comparisons to the pre-transit biofouling status.

Objectives

Our aim was to characterize the biofouling assemblages on the underwater surfaces of both vessels upon arrival at their final destination (Brownsville, Texas). More specifically, we conducted underwater surveys and sample analyses to provide direct comparisons to the pre-transit surveys that were carried out in Suisun Bay, California. Based upon these data, we tested for differences in biofouling metrics (percent cover, assemblage similarity, and species occurrence) between times (pre- vs post- transit), vessels, depths and locations on the hull.

METHODS

Vessel Surveys

Vessels were surveyed using a commercial diver and surface support team on a dive boat in the Port of Brownsville, Texas. The vessels departed San Francisco Bay, on a tandem tow, on February 14th 2006. The FLORENCE arrived at dockside in Brownsville

43 days later on March 29th. The POINT LOMA was docked on April 1st 2006. The surveys of the FLORENCE and POINT LOMA occurred on March 30th and April 2nd 2006, respectively. Surveys were conducted using our standard sampling protocol (see Davidson et al., 2006). Briefly, the diver sampled each vessel, collecting photographic images and biological samples, in a stratified sampling scheme by hull location. Photo-quadrats were taken using a video camera with still images captured from the DVD at a later date. A Clearwater box was not available for use as it had been in Suisun Bay so the diver used a 6-inch diameter quadrat as the frame for the images. This proved satisfactory since visibility enabled us to image a comparable area (photo-quadrats) to that used in the pre-transit surveys. Although the resulting images were not as consistent, (in terms of lighting, angle, and field-of-view) as the pre-transit survey, this did not prevent accurate estimates of percent cover but simply required extra effort to analyze the photographs. Replicate biological samples were collected by removing all macro-organisms from areas measuring six square inches (231 cm²) and placing them into individually labeled zip-lock bags. Samples were taken from within a one-meter distance of the corresponding photo-quadrat for that location. Photo-quadrats and samples were taken in the same locations as the pre-transit survey: propeller, rudder, propeller shafts, struts, transverse hull transects and sea chests (Davidson et al., 2006). Overall, 92 samples were collected and 99 photo-quadrats were taken across both vessels.

Sample Processing, Taxonomy & Analyses

Preliminary sorting of biological samples was done as soon as possible at dockside for both ships to determine the condition of collected organisms as either alive or dead. Our goal was to determine whether living specimens of each species were present or absent. This was accomplished by sifting through material in the samples and vouchering specimens of each morpho-species that were alive. Detailed note taking, labeling and sample preservation were also carried out on dockside. Samples were preserved in 95% ethanol and shipped (HazMat shipments) to SERC's laboratories in Maryland and California where detailed processing took place using a standardized protocol (see Davidson et al. [2006] for further description). Voucher specimens were sent to expert taxonomists for identification.

Based upon analysis of the survey data, a data matrix was constructed for the biological samples and photo-quadrat data collected on each vessel. The biological samples data, a presence/absence matrix of taxa, was used for univariate and multivariate analysis to characterize the associated species richness and biofouling community. For the photo-quadrat data, the matrix consisted of the percent cover (as estimated by point count methods described in Davidson et al., 2006) per quadrat for each of eight distinguishable categories: barnacle, dead barnacle, encrusting spp, branching spp (labeled bryozoan in the previous report), paint/hull, biofilm, polychaete tube, organism scars, algae, and 'other'. Each of these categories corresponded to those used in the pre-transit analysis, some of which were zero in the pre-transit data matrix.

Univariate analysis was carried out on species occurrences and percent cover per photo-quadrat. Multivariate analysis, using the PRIMER program (Primer-E Ltd., 2002), was done to assess how assemblage organization differed between survey, ships, depths and locations. Ordinations were carried out using the multi-dimensional scaling (MDS) technique, which produces a plot revealing sample similarity: points close together in the plot are compositionally similar while those far apart are dissimilar. The analysis of similarities (ANOSIM) test was used to test if significant differences existed between these factors. The test statistic (R) is usually a value between 0 and 1 with greater than 0.6 showing groups of samples are clearly distinguishable and dissimilar in terms of assemblage composition whereas values less than 0.3 mean that groups of samples are similar in composition (Clarke & Gorley, 2001). A species accumulation curve (using 999 random permutations of sample order) was generated to compare pre- and post-species richness and assess the completeness of the species inventory.

One temperature logger (HOBO brand) was attached to each ship during the pre-transit survey to determine water temperature variability throughout the voyage. The temperature was recorded at five-minute intervals for POINT LOMA and 16-minute intervals for FLORENCE. Each logger was retrieved upon arrival to Brownsville, and data were downloaded for further analysis.

RESULTS & DISCUSSION

Environmental fluctuations en-route

The voyage between California and Texas took approximately 43 days. The vessels were towed from San Francisco Bay and traveled in a southeasterly direction to the Panama Canal and then northwesterly toward Brownsville (fig. 1), transiting a maximum latitudinal range of 32°. During this time period, biofouling organisms encountered physical disturbance from wave and swell action while at sea as well as sheer forces from the vessels' propulsion. Sea conditions were reported as calm throughout the voyage and tow speeds were recorded between 4.9 and 7.9 knots (averaging 6.4 knots over 24 daily reports). In addition, organisms encountered salinity variation that ranged between zero (Panama Canal) and at least 37 parts per thousand (Brownsville) and temperatures that varied between 9.89°C and 31.56°C.

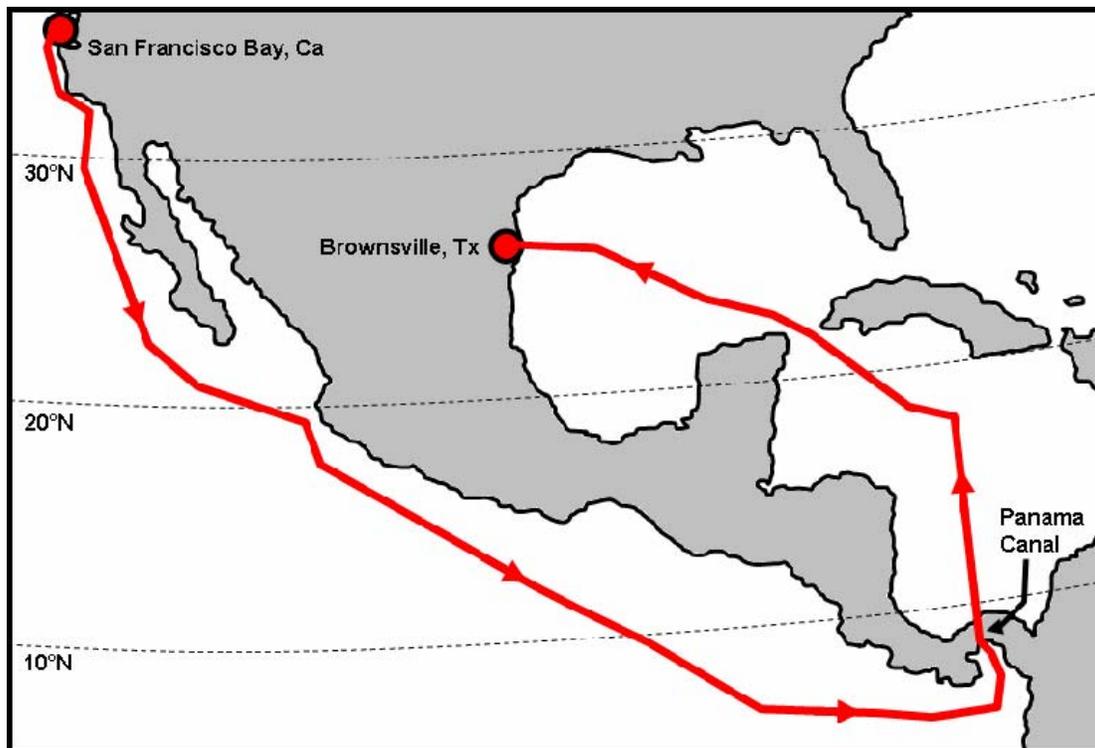


Figure 1. The voyage route of POINT LOMA and FLORENCE. The vessels took 43 days to travel over 5000 nautical miles between San Francisco Bay, California and Brownsville Texas, via the Panama Canal.

The temperature signal throughout the voyage reflected numerous stages of the journey (described here for the FLORENCE but reflective of both ships). The first 9

days (14th to 23rd of February) showed a moderate increase in temperature as the voyage proceeded southward along the coast of California and Mexico (fig. 2). From the 23rd to the 27th of February, when the vessel traveled from approximately 23°10'N to 15°30'N, a more rapid temperature increase with diel fluctuations was recorded. This was followed by a period where temperatures varied between 24°C and 31°C prior to the ships entering the Panama Canal. Upon entry to the Canal (03/09/06), the temperature plummeted by 6°C in less than two hours as the ships passed through the locks of the canal. Similarly, departure from the canal resulted in a 7°C increase in temperature over a two-hour period (03/17/06). As the ships traveled north toward Brownsville, there was a noticeable decrease in temperature on March 25th as they neared their destination (fig. 2).

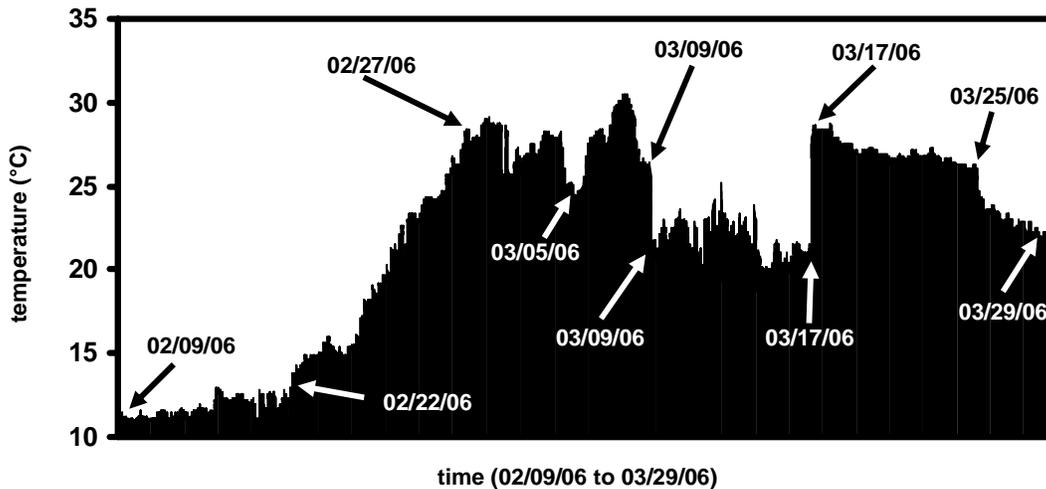


Figure 2. The shipside sea-water temperature recorded throughout the voyage. This plot shows the temperature recordings from the logger attached to the outer hull of the FLORENCE. Dates are included throughout the plot to highlight points referred to in the text.

We were unable to collect a similar data set for salinity but previous published data shows that the Pacific and Atlantic entrances to the canal vary between 16 to 30 ppt, while Miraflores Lake and Gatun Lake range between 0.005 and 3 ppt (Hildebrand, 1939; Menzies, 1968; Jones and Dawson, 1973). The expected range in salinity fluctuation experienced during the voyage was clearly greater than that encountered in Suisun Bay, with a reported range from 0-20 ppt (Davidson et al., 2006). The temperature maximum (and rates of change) was also much greater during the voyage than would have been encountered in Suisun Bay during the summer.

Biofouling on the vessels upon arrival in Brownsville

A. *Biological Samples: Community Composition and Species Richness*

There were 57 distinct taxa (hereafter referred to as species) recorded from the 92 biological samples collected from both vessels (table 1). Live specimens were observed for 22 of the 57 species, including all of the spatially dominant species (those occurring in greater than 10% of biological samples). Surprisingly, there were only 22 species recorded during the pre-transit surveys of these same vessels, at least ten of which were not encountered in the post-transit surveys (see Table 1 and Davidson et al., 2006). Thus, of the 57 species collected in the post-transit surveys, at least 43 were not previously recorded on these ships. Thirteen species were recorded from more than 15% of samples collected, and the majority of the remaining 44 species were spatially rare, being recorded in fewer than 5% of samples. At least 23 of the ‘new’ species recorded were singletons or doubletons – species recorded from only one or two samples, respectively. This rarity is also reflected in the species accumulation curve for the post-transit survey, which did not approach asymptote (fig. 3). The clear inference from this plot, comparing similar sampling efforts for pre- and post- transit surveys, is that our surveys underestimated the number of species present and (as above) that there were noticeably more species found in the latter surveys.

Both the bryozoan, *Conopeum osburni*, and the barnacle, *Balanus improvisus*, which were present in approximately 98% of biological samples collected in Suisun Bay, were recorded in almost 98% of samples in Brownsville as well (table 1). Two additional barnacles, *Balanus amphitrite* and *Lepas pacifica*, were recorded in post-transit samples only. It is possible that both settled on the vessels during the slow transit along the Pacific coast of California because these species do not occur in low-salinity estuaries. Of the other species that were encountered in Texas but not in Suisun Bay, many that were rare (found in fewer than 5% of samples) may simply have been undetected in the pre-transit surveys or could have attached to the ship during transit as many are established in Gulf of Mexico waters (table 1).

Table 1. Species recorded in biological samples. A list of 57 distinct taxa (species or species groups) is provided with frequency of occurrence (percent of samples) from pre- and post- transit surveys. Also recorded is whether or not live specimens were found for each taxon during the preliminary sorting (see text for explanation) and the biogeographic status of species in Texas waters.

taxon/common name	lowest taxonomic level	post-transit % samples	pre-transit % samples	live vouchers?	status in texas - NIS, native or cryptogenic
bryozoan	Conopeum osburni	97.8	98.0	yes	NIS
bryozoan	Bugula sp (B. neritina?)	2.2	0	no	cryptogenic
barnacle	Balanus improvisus	97.8	98.0	yes	native
barnacle	Balanus amphitrite	<21.7	0	yes	NIS
goose-neck barnacle	Lepas pacifica	1.1	0	no	NIS
isopod	Gnorisphaeroma oregonense	25.0	73.7	yes	NIS
isopod	Gnorisphaeroma insulare	2.2	73.7	no	NIS
isopod	Cirolanidae sp	1.1	0	no	native species present
isopod	Sphaeromatidae sp	3.3	0	yes	native species present
amphipod	Elasmopus sp	15.2	0	yes	native species present
amphipod	Ericthonius brasiliensis	31.5	0	yes	native
amphipod	Stenothoe valida	26.1	0	yes	native/cryptogenic
amphipod	Laticorophium baconi	2.2	0	no	NIS
amphipod	Photidae	2.2	0	no	native species present
amphipod	Monocorophium acherusicum	5.4	0	no	native?
amphipod	Sinelobus stanfordi	5.4	0	no	native/cryptogenic
amphipod	Gammaridea sp A	3.3	?	no	native/cryptogenic
amphipod	Jassa sp	1.1	0	no	native species present
amphipod	Hyalidae sp	1.1	0	no	native species present
amphipod	Melita nitida	1.1	84.8	no	native
amphipod (caprellid)	Caprella sp	1.1	0	no	native species present
copepod	Paracalanus sp	5.4	0	no	native species present
copepod	Parvocalanus crassirostris	1.1	0	no	native
copepod	Nannocalanus minor	1.1	0	no	native
copepod	Calanoida copepodid	1.1	0	no	native species present
copepod	Candacia bipinnata	1.1	0	no	native
copepod	Acartia tonsa	1.1	0	no	native
copepod	Labidocera aestiva	1.1	0	no	native
copepod	Undinula vulgaris	1.1	0	no	native
copepod	Harpacticoida sp	5.4	1.0	yes	native species present
decapod	Pachygrapsus transversus	3.3	0	yes	native
decapod	Brachyura zoea	4.3	0	yes	native species present
decapod	Porcellanidae zoea	2.2	0	no	native species present
decapod	Caridea spp	6.5	0	no	native species present
mysid	Mysid sp	3.3	0	no	native species present
mayfly larva	Ephemeroptera larva	1.1	3.0	no	native species present
oyster	Ostreidae sp	2.2	0	no	native species present
bivalve mollusc	Bivalve sp A (clam-like)	1.1	?	no	?
marine snail	Gastropoda A (Alia sp?)	2.2	0	yes	?
marine snail	Gastropoda B	1.1	0	no	?
hydroid	Turritopsis nutricula	2.2	67	yes	native
hydroid	Cuspidella sp	88.0	0	yes	cryptogenic
hydroid	Clytia hemisphaerica	20.7	0	yes	cryptogenic
hydroid	Clytia sp	67.4	0	yes	NIS/Cryptogenic
hydroid	Garveia franciscana	45.7	0	yes	NIS
hydroid	Obelia sp?	25.0	0	yes	cryptogenic
hydroid	Opercularella lacerata	2.2	0	no	NIS/Cryptogenic
anemone	Anthozoa B	2.2	?	yes	?
ascidian	Colonial tunicate (Botryllid?)	2.2	0	no	native species present
ascidian	Solitary tunicate	3.3	0	yes	native species present
polychaete worm	Nereididae sp	2.2	6.0	no	native species present
polychaete worm	Polydora sp	2.2	0	no	native species present
polychaete worm	Syllidae sp	2.2	1.0	no	native species present
polychaete worm	Polychaete sp A	1.1	?	yes	?
flat worm	Platyhelminthes sp	1.1	0	no	native species present
green algae	Chlorophyta A	8.7	0	yes	?
algae	Algae B	1.1	0	no	?

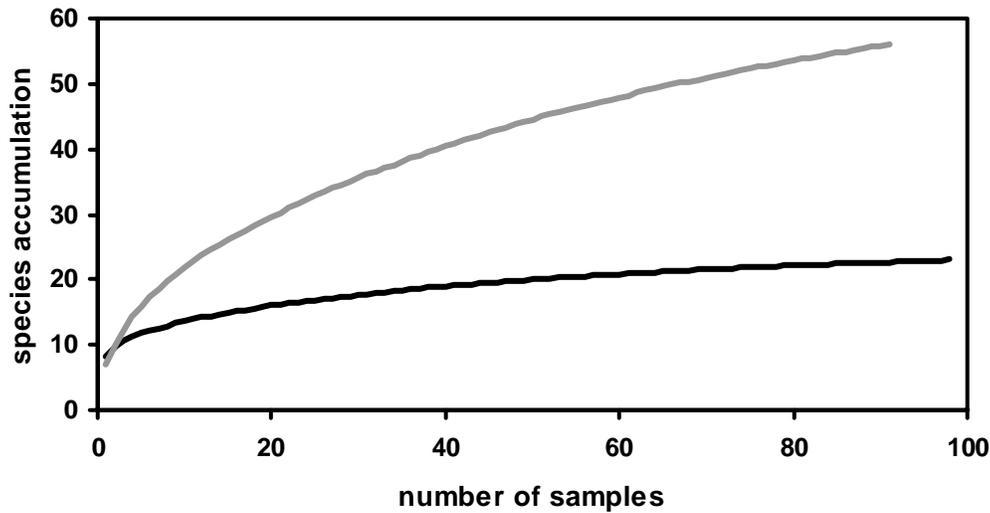


Figure 3. Species accumulation curves for pre- and post-transit surveys. The pre-transit (black) and post-transit (grey) species accumulation curves are plotted using the presence/absence data from the sample collections. Neither curve reaches asymptote but the pre-transit survey appears comparatively more complete because of fewer rare species.

Five species of hydroid (table 1) not previously recorded during pre-transit sampling were surprisingly prevalent. These species are usually reported from higher salinity conditions than occur in Suisun Bay. It is highly unlikely that these hydroids occurred at such prevalence (and size) and were missed in the pre-transit survey, and we re-analyzed a subset of pre-transit samples to confirm this was the case – detecting no specimens of these taxa. It is noteworthy that the hydroids found in Brownsville were generally small, suggesting either (a) recent settlement during transit or upon arrival to Brownsville or (b) new growth of recent recruits or dormant remnant colonies from Suisun Bay.

We detected multiple mobile crustacean taxa, many of which may have settled on the vessel during the transit and while in port in Brownsville. Because the complex, 3-dimensional matrix of fouling was greatly reduced (see next section), some of the mobile species that inhabited the matrix were probably removed during the voyage. Many of the copepods and amphipods are established (both native and non-native) in the Gulf of Mexico. The isopod *Gnorisphaeroma oregonense*, however, survived the voyage and was present in 25% of samples taken across both vessels. This species is native to the Pacific coast of North America and does not occur in Texas waters. There were also at

least six other nonindigenous species to the Texas coast found on the ships (table 1), but no determination can be made at present regarding their possibility for establishment. Additional descriptions of the frequently occurring species encountered on the hulls from the post-transit survey are included in Appendix A. Those species that were already encountered in Suisun Bay have been described in the previous report (Davidson et al., 2006).

The Florence had significantly more species per biological sample than the POINT LOMA when they arrived in Brownsville (fig. 4), but there was no significant difference between depths (2-way ANOVA; ships, $F = 6.9$, $p < 0.01$; depths, $F = 0.48$, $p > 0.1$; interaction, $F = 1.73$, $p > 0.1$). This difference was reflected in the assemblage organization between both vessels. An ordination of the samples data showed a small but significant difference between vessels, with samples from each ship grouping together (fig. 5A), and the difference was partially due to higher numbers of species per sample on the FLORENCE (fig. 5B). In addition, it is noteworthy that we observed substantial amounts of sediment in the sea chest of the POINT LOMA during the pre-transit survey, and that this was greatly reduced during transit, arriving to Texas without a collectable amount.

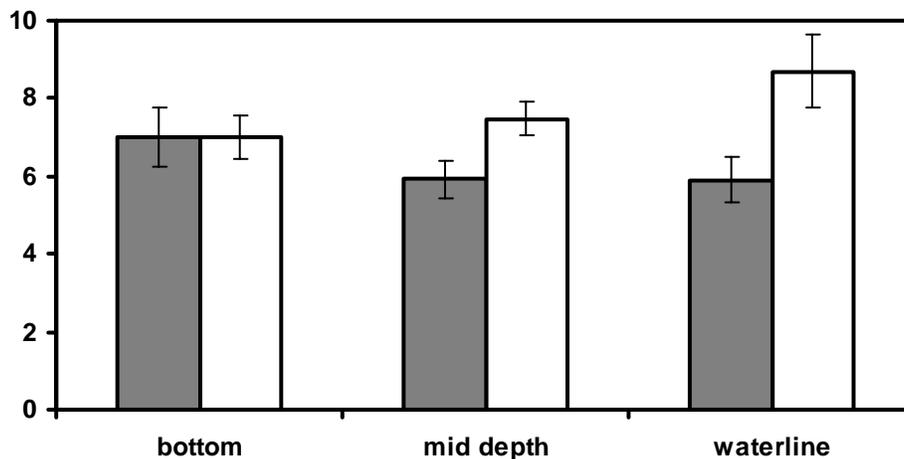


Figure 4. Mean number of species per quadrat across vessels and depths. The mean species density per biological sample from the POINT LOMA (dark grey) and FLORENCE (white) is plotted per depth. There was no significant difference between depths but the FLORENCE had significantly more species per sample than POINT LOMA.

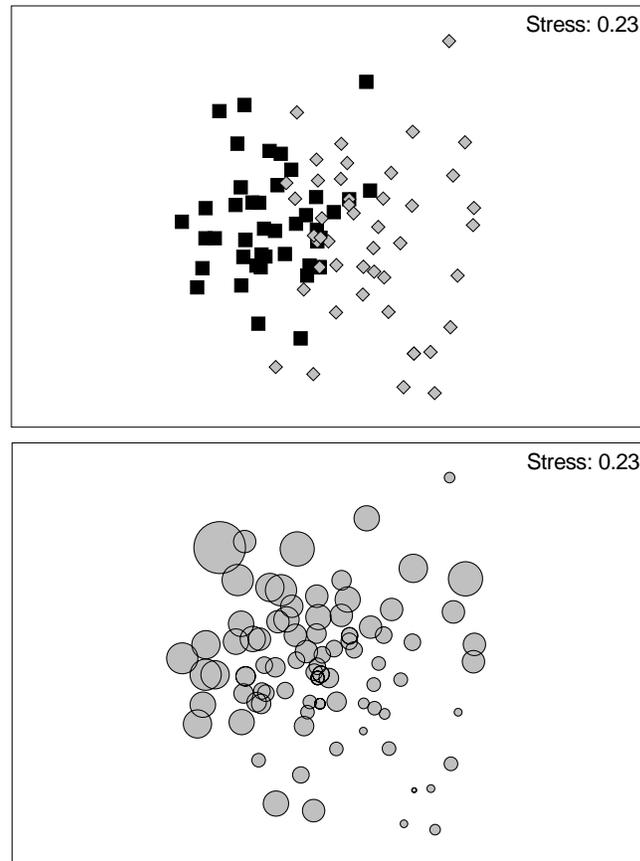


Figure 5. Differences between ships in assemblage structure and species density. The MDS plot (A) of Florence (black squares) and POINT LOMA (grey diamonds) reveals minor differences between both vessels in terms of species composition (ANOSIM, $R=0.21$, $p<0.01$). The same plot using bubbles to represent species density per sample (B) shows that a higher number of species per samples explains some of this variation between ships. The plots were generated using the sample collection data and Bray-Curtis similarity.

B. Photographic Quadrats: Percent Cover

The photo-quadrat analysis revealed that there were differences in percent cover of organisms among locations on the ships: specifically, the areas on the hull near the bow had higher percent cover of paint/hull than other locations (fig. 6). The samples in the bow areas also had higher percent covers of organism scars. The observed difference between depths in the pre-transit survey, whereby the cover of *C. osburni* was lower at shallower locations (Davidson et al., 2006), was not observed in post-transit surveys after the ships arrived in Texas (fig. 6A). However, end-point densities of branching species were highest at bottom depths (keel, flat bottom) compared to mid or waterline depths (fig. 7).

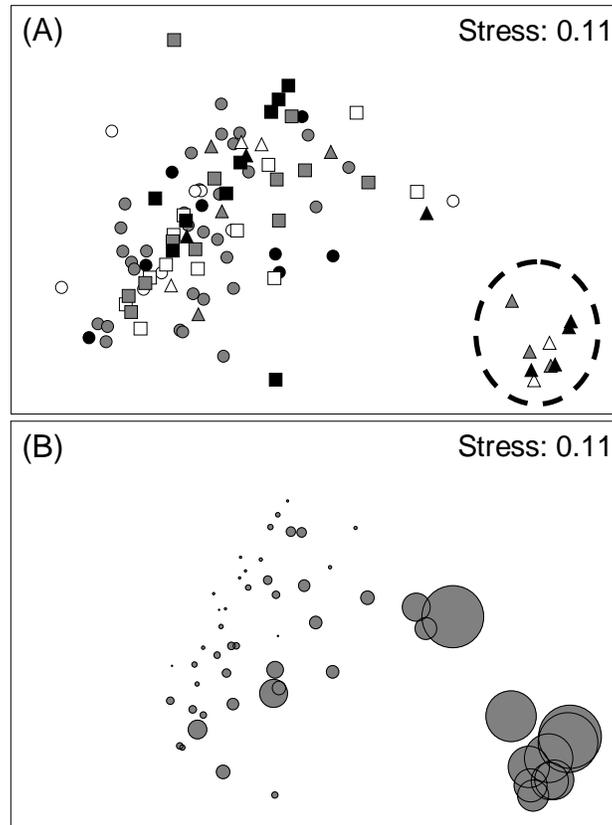


Figure 6. The assemblage organization of biofouling on ships upon arrival in Texas. (A) The plot shows the MDS of photo-quadrats (samples) and the relative similarities of samples to each other. Those close together are similar in composition whereas those far apart are dissimilar. White, grey and black symbols represent waterline, mid and bottom depths respectively. Circles, squares and triangles represent aft, midship and forward locations on the vessels, respectively. Note the separation of bow samples (dashed circle) from the other samples taken at other ship locations. (B) The same plot as above but with bubbles representing the samples showing the gradient of paint/rust percent cover per sample. A similar pattern of distribution among samples was observed for scars/remnants.

More broadly, clear differences existed in the pre-transit versus post-transit photographic surveys. The most striking change was the reduction of the bryozoan mat, which occurred at thicknesses of 2-5 cm during pre-transit surveys, but had little vertical structure in post-transit surveys. Although the reduction in the branching form of the dominant bryozoan, *C. osburni* was the most obvious difference observed between pre- and post-transit surveys, it was still recorded in 97.8% of the samples collected. Quantitative comparisons across depth zones (waterline, mid depth and bottom depth) between pre- and post-transit percent cover estimates of eight categories (fig. 7) revealed: 1) significant and substantial reductions in percent cover of branching species

(mainly *C. osburni*) at three depths; 2) significant decreases in live barnacle cover and increases in dead barnacle cover; 3) small but significant increases in both encrusting species and biofilm; 4) significant increases in non-living remnants of organisms (residual barnacle markings or scars mainly), which were not evident in pre-transit surveys; and 5) significant increases in paint/hull percent cover at mid and bottom depths.

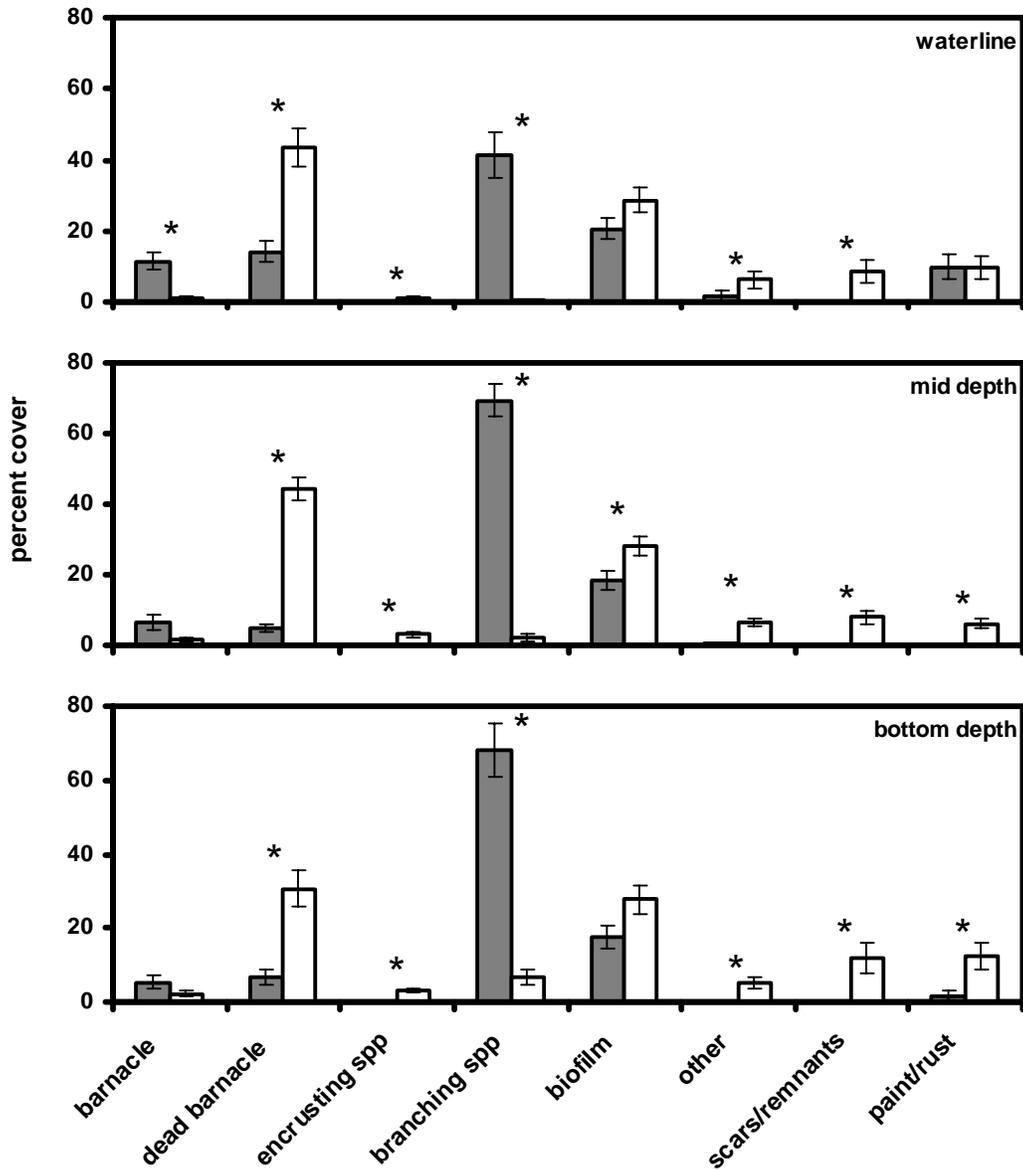


Figure 7. Differences in biofouling percent cover between pre- and post- voyage surveys. The mean (+/- S.E.) percent cover of the eight main categories of biofouling estimated from photo-quadrats is plotted for pre- (dark grey) and post- (white) transit surveys at three depths. An asterisk above each pair-wise comparison denotes significant differences (Mann-Whitney Test, all $p < 0.01$).

Numerous possible causal effects may explain each of these changes. It is important to highlight that the loss of branching species (1) and increase in bare space (5) are due to the effect of the voyage alone. In contrast, the increase in dead barnacles (2), encrusting organisms (3), and organism scars (4) may be due partly to the removal of 3-dimensional/vertical fouling, which increased the visibility of a primary fouling layer that was previously obscured by a thick mat of bryozoans. Certainly, some organisms may also have settled (3) or been lost to the underwater surfaces of both vessels during the 43+ days between the surveys.

An ANOSIM test revealed that there were substantial and significant differences in biofouling assemblage organization between pre- and post- transit surveys ($R = 0.6$, $p < 0.01$, fig. 8A). These differences were largely due to the reduction in branching species, which dominated percent cover across many areas of the ships' hulls in Suisun Bay (fig. 8B). An increase in bare space and organism scars/remnants also played an important role in differentiating between the biofouling assemblages between pre- and post- transit (fig. 8C), as did an increase in dead barnacle cover (fig. 8D). Such substantial differences were not observed from the sample collection data because the reduction in organism (or functional group) abundances or biomass rather than changes in species presence/absence produced stronger patterns.

Overall, there was a clear reduction in biomass between pre- and post-transit surveys that we attribute to physical removal, especially of the 3-dimensional structure associated with the bryozoan, *C. osburni*. This should serve to reduce the risk of species transfer and subsequent invasion, although the magnitude of risk has not been evaluated in this assessment. However, it is also important to note that many different taxa were detected in post-transit surveys and that survivorship to this stage was confirmed for many of these organisms, especially for widespread species. While sheer biomass and percent cover decline between sampling events, an average of six species per quadrat were present in the post-transit surveys and cumulative species richness was 57 different taxa, which was possibly an underestimate given the shape of the species accumulation curve (albeit a curve based on presence/absence data). Since a subset of these species is not known to occur in the coastal waters of Texas, the possibility of establishing non-native founder

populations exists. Moreover, some of these species are already established in the western Gulf of Mexico, but introduction of different genotypes may also be of concern, because they may cause shifts in ecological characteristics, community dynamics, and impacts as has been documented previously.

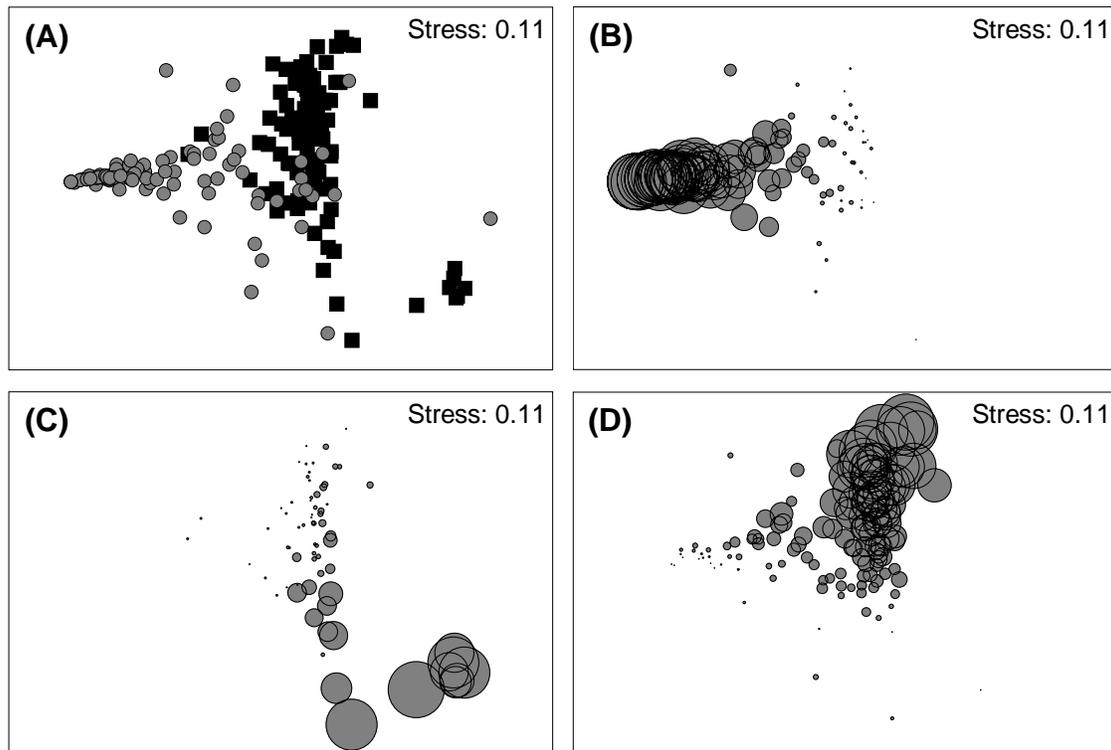


Figure 8. A comparison of biofouling assemblage organization between pre- and post-transit. (A) MDS plot showing the division between pre- (grey circles) and post- (black squares) voyage samples using photo-quadrat data. Parts (B), (C), and (D) show the same plot with bubble sizes representing the prevalence of branching spp (mainly the bryozoan *C. osburni*), organism scars/remnants and dead barnacles, respectively. The three bubble plots reveal gradients that explain the variation in biofouling between pre- and post-transit: the branching bryozoan dominated samples in the pre-transit survey but was absent or very much reduced in abundance during the post-transit survey; and there were higher percent covers of organism scars and dead barnacles in the post-transit samples.

Furthermore, we note that similar movements of ships from the same source region (Suisun Bay) and along the same route will undoubtedly involve many more taxa than documented in this pilot study. This is expected simply from temporal variation in the biota on vessels at the source port, associated with seasonal changes in environmental conditions (especially salinity and temperature), and also inter-annual variation. Moreover, there is undoubtedly variation in survivorship during the voyage and at the recipient port.

The current study provides a snapshot of one movement event, restricted to one season and voyage, and it therefore does not address or estimate the full range of measures needed to assess risk of invasion at this time. It is a certainty that some organisms can withstand such environmental changes as observed during this transit, and also that some taxa are physiologically capable of establishing populations in both Texas and California bays – based on the wide biogeographic ranges observed for some organisms. We already know that numerous species that occur in San Francisco Bay are not present in Texas. However, the frequency with which these are transferred by MARAD vessels (moved in different seasons and different transit conditions) and the environmental tolerance (i.e. capacity to colonize) of these organisms are not presently known. These represent present critical gaps in knowledge and clear priorities for estimating associated invasion risk.

SUMMARY & CONCLUSIONS

- 1) A post-transit survey and analysis of biofouling on the Reserve Fleet vessels POINT LOMA and FLORENCE was carried out in Brownsville, TX after a similar survey had been conducted prior to their departure from Suisun Bay, California.
- 2) The environmental conditions encountered on the voyage were very different to those that the hull fouling organisms experienced in Suisun Bay. In particular, the ranges and rate of change in salinity and temperature probably had significant effects on species; temperature ranged from 9.8°C and 31.5°C and salinity ranged from 0-37 ppt. Rapid changes in both were encountered when the ships passed through the Panama Canal. Vessel movement and sea conditions were probably also significant factors in reducing biofouling cover on the hulls.
- 3) There was a significant difference in biofouling assemblage organization between pre- and post- transit surveys. The voyage had the effect of removing much of the vertical growth of fouling abundance and clearing fouling altogether from the bow areas of both ships. However, there was a higher number of species recorded on the vessels in Brownsville (57) compared to the surveys in Suisun Bay (22).

- 4) The most striking difference between pre- and post- transit surveys was the reduction in the 3-dimensional/vertical fouling matrix, particularly the branching species including the bryozoan *Conopeum osburni*. This reduction in biomass was not reflected in presence/absence analysis of samples where *C. osburni* was still found in $\approx 98\%$ of samples collected across both vessels.
- 5) Numerous species, particularly hydroids and crustaceans, were widespread on the hulls during the post-transit survey but were absent from the pre-transit survey. It is possible that these species attached to the hull during the transit. It is also possible that these were present as new recruits or dormant, indescript stages (e.g. small stolons) in Suisun Bay. Other species that were found in fewer than 5% of samples may have attached to the hull or may simply have not been encountered in Suisun Bay.
- 6) There were significant differences between ships in terms of species density per sample (POINT LOMA had significantly fewer species per sample) and between pre- and post- transit surveys in terms of functional categories analyzed from photo-quadrats. The differences between depths was not as strong as in Suisun Bay, mainly because of the reduction in 3-dimensional/vertical growth, although the end-point percent cover of branching species was highest at bottom depths (flat bottom, keel).
- 7) Although biomass was observed to be greatly reduced upon arrival in Texas, the possibility remains that organism removal from the ships' hulls occurred in coastal zones along their route and posed a threat of propagule supply and bioinvasion to these regions.
- 8) Of the species that were recorded on the hulls in Texas, at least seven are non-native to the western Gulf of Mexico, and two of these are known to be already established there. Many of these are cryptic species whose impact to native communities is not well studied. The Asian clam, *Corbula amurensis*, which has a history of invasion that has lead to significant changes in the benthic community and food web structure in San Francisco Bay, was not found (alive) on the vessels upon arrival in Texas.

- 9) Overall, the expected reduction in organism biomass was observed, and we attribute this to the effect of the voyage from California to Texas. The thick matrix of biofouling that was present in Suisun Bay was removed during the tow. However, we still detected 56 taxa upon arrival to Texas, and many of these organisms were alive, indicating an opportunity for invasion exists.
- 10) This study should be viewed as a “snapshot” of a single transfer event, which is repeated across several source ports and seasons, and it cannot be viewed as representative of all obsolete vessel movements. Instead, we expect considerable variation to occur in the starting community and survivorship of associated organisms.
- 11) Determining the level of risk posed by obsolete vessel movements requires comprehensive study of three important stages in their transfer: 1) studies of the fleet sites and the fouling extent and composition of the vessels; 2) more replicated before-and-after transit sampling to evaluate the effect of towing on biofouling extent and composition; and 3) experiments and observation of organism viability and reproductive capability at destination regions.

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Appendix A

The following descriptions are for those dominant species that were recorded in the post-transit survey and not in the pre-transit survey. Species found in the pre-transit survey are described in Davidson et al. (2006).

<i>Balanus amphitrite</i>

Balanus amphitrite Darwin 1854 (Striped Barnacle)

Synonyms- *Balanus amphitrite* var. *communis* Darwin 1854; *Balanus amphitrite* ssp. *amphitrite* Darwin 1854; *Balanus amphitrite* forma *hawaiiensis* Broch 1922; *Balanus amphitrite* ssp. *venustus* Sundra Raj 1927; *Balanus amphitrite* var. *denticulata* Broch 1927; *Balanus amphitrite* var. *aeratus* Oliveira 1941; *Balanus amphitrite* var. *fluminensis* Oliveira 1941; *Balanus amphitrite* var. *cochinensis* Nilsson-Cantell 1938; *Balanus amphitrite* ssp. *franciscanus* Rogers 1949; *Balanus amphitrite* ssp. *herzi* Rogers 1949;

Taxonomy Comments- This species is a member of the *Balanus amphitrite* species complex and has been confused with *B. venustus* and other members of the complex, such as *B. pallidus*, *B. variegatus*, and *B. reticulatus* (Henry and McLaughlin 1975)

Native Range- Indo-West Pacific, but limits of native range are uncertain due to frequent ship transport (Darwin 1854; Utinomi 1960; Henry and McLaughlin 1975).. Apparently introduced in northwest Pacific (Japan, Korea, Vladivostok area, Russia- Utinomi 1960; Kim 1992; Zvyagintsev 2003), possibly native in Mediterranean, present in excavation of a Roman naval base in Italy (Southward 1998).

Invaded Range- NW Atlantic (Chesapeake Bay-Caribbean, including the Gulf of Mexico and the Texas coast- Henry and McLaughlin 1975, Gittings 1985); SW Atlantic (Brazil-Argentina- Young 1994; Orensanz et al. 2002); NE Atlantic (Azores, Spain-England-Netherlands, associated with heated effluents in England and Netherlands- Bishop 1950; Southward 1998; Wolff 2005); NW Pacific [Korea-Japan-Russia (Vladivostok area- Utinomi 1960; Kim 1992; Zvyagintsev 2003); SW Pacific (southeast Australia?; New Zealand- (Jones 1992; Cranfield et al. 1998); NE Pacific (Panama to Ventura Harbor, California; San Francisco Bay

Invasion Date- 1939- San Francisco Bay; 1931- Gulf of Mexico

1st Records- CA/San Francisco Bay (1939, Rogers 1939, cited by Carlton 1979; Dry Tortugas/FL/Gulf of Mexico (as *B. a. hawaiiensis*, USNMNH specimen 155404.); Corpus Christi/TX/Corpus Christi Bay (1971, Gittings 1985)

Probable Vector(s) Fouling; Ballast Water

History of Spread-

Balanus amphitrite (Striped Barnacle) appears to have invaded North American waters in the 20th century (Zullo 1966; Southward 1975). It is “extremely common on ship's bottoms” (Darwin 1854), and appears to have been introduced over much of its present range, including most of the Atlantic Basin (cryptogenic in the Mediterranean?) and the Eastern Pacific, including Hawai'i, and the North American Coast, from Panama to San Francisco Bay (Zullo et al. 1972; Henry and McLaughlin 1975; Cohen and Carlton 1995).

Balanus amphitrite was first collected in Hawai'i in 1902, and on the coast of California (La Jolla) in 1921. On the Pacific Coast of North America, it is abundant on the coast of Panama and ranges at least as far north as San Francisco Bay. Its usual habitats are the sheltered waters of harbors. There is an apparent gap in its range between Santa Monica Bay and San Francisco Bay (Carlton 1979; Wasson et al. 2001; Cohen et al. 2002), where it was first collected in 1938. In San Francisco Bay, it is confined to the warmest parts of the estuary (Zullo et al. 1972).

Darwin (1854) reported *Balanus amphitrite* as occurring in the Caribbean, but the identity of his specimens is uncertain. The earliest verified record from the Northwest Atlantic is a specimen collected from the Dry Tortugas, Florida, in the Gulf of Mexico in 1931 (U.S. National Museum of Natural History collections). The Striped Barnacle was common at Beaufort, North Carolina in 1955 (Zullo 1966; Henry and McLaughlin 1975), and occurs on the East Coast from Virginia Beach, Virginia (1967) to Biscayne Bay, Florida (Henry and McLaughlin 1975; Ruiz et al., unpublished data). This barnacle may occur sporadically further north, but apparently cannot survive the winter. Specimens were collected from a ship hull in New York harbor in 1925 (U.S. National Museum of Natural History collections). Zullo (1966) collected four specimens from pilings near Hyannis, Massachusetts, on Cape Cod, and maintained them in a running seawater system—they died when temperatures dropped to 1.5°C.

On the Gulf Coast, *B. amphitrite* has been collected from the Dry Tortugas and Boca Ciega Bay (in Charlotte Harbor), Tampa Bay, St. Andrews Bay, Aransas Bay, Corpus Christi Bay, and the Laguna Madre, Texas (Wells 1966; Henry and McLaughlin 1975; Gittings 1985). It also occurs in Bermuda, and in the wider Caribbean, south to Trinidad and Curaçao and east to the Bahamas and Windward Islands (Henry and McLaughlin 1975; Southward 1975; Bacon 1976).

Life History-

Maximum temperature, Adult- 40°C (Ritz and Foster 1968)

Minimum temperature, Adult- 1.5° C (Field, Experimental- Zullo 1966; Werner 1967)

Optimum Adult survival range, temperature- 10-30° C

Maximum salinity, Adult- 52 ppt (Field observations, Cohen 2005).

Minimum salinity, Adult- 10 ppt (Experimental, Anil et al. 1995).

Optimum Adult survival range, salinity- 20-40 ppt

Maximum temperature, reproductive- 32° C (Experimental, highest tested, Patel and Crisp 1960)

Minimum temperature, reproductive- 15° C (Experimental, Anil et al. 1995).

Optimum reproductive range, Temperature-**Maximum salinity, reproductive-** 44 (Field observations, Shalla et al. 1995)**Minimum salinity, reproductive-** 10 ppt (Experimental, Anil et al. 1995).**Optimum reproductive range, salinity-****Egg type-** Brooded (Barnes 1974)**Larval type-** Planktotrophic, nauplius → cypris (Barnes 1983)**Larval Duration-** 18 days, at 15°C to 6 days at 30°C, (Anil et al. 1995)**Reproductive Season, Suisun Bay-****Size at settlement-****Adult Mobility type-** Sessile Epifauna**Life History Comments-**

Temperature- *Balanus amphitrite* appears to be confined to warm-temperate waters. The minimum survival temperature comes from an observation of 2 individuals in running seawater, at Woods Hole MA (Zullo 1966). In air at 0°C, 50% of adults from Florida survived for 22 days (Werner 1967). The maximum survival temperature was the temperature at which 50% of the barnacles (from New Zealand) went into “coma” (lack of response to pricking with a needle), when heated 1°C per minute (Ritz and Foster 1968). Observed minimum reproductive temperatures were 17°C for barnacles from heated docks, UK (Patel and Crisp 1960) and 15°C for barnacles in culture from Japan (Anil et al. 1995).

Salinity- The lower salinity limits were experimental (Anil et al. 1995). The upper salinity limits were based on field observations in a pond, Alviso CA, South San Francisco Bay (Cohen 2005). In the Loxahatchee River estuary, Indian Lagoon, Florida, *B. amphitrite* was abundant at sites with average salinities of 30-32 ppt, and common at average salinities as low as 19 ppt (SEM ± 3 ppt) (McPherson et al. 1984).

Development: Larval Form - *Balanus amphitrite* has seven larval stages, as in other Thoracica: a non-feeding Nauplius I, feeding nauplius stages II-VI, and nonfeeding cypris, the settling stage (Costlow and Bookhout 1958). Larval development period is based on laboratory culture of animals from Hamana Bay, Japan (The longest larval development, 16-18 days, was observed at 15°C, the shortest, 7-10 days, at 30°C. Development was slower at 10 ppt than at 20 and 30 ppt (Anil et al. 1995).

Community Ecology-**Adult Horizontal Habitat type-** Rocky, Coarse Woody Debris; Marinas and Docks, Oysterbeds, Mangroves, Canals, Vessel Hulls**Adult Vertical Habitat type-** Epibenthic**Tidal Zone Range-** Subtidal, Low Intertidal; Mid-Intertidal**Trophic Status-** Suspension feeder**Food-** Phytoplankton, Detritus**Competitors-** Other Bivalves, Other Barnacles, Bryozoans**Predators-** Crabs, Flatworms, Carnivorous Snails, Starfish

Impacts**Ecological Impacts-** Herbivory, Competition, Habitat Change**Economic Impacts-** Fisheries/Game, Shipping, Industry**Impact Comments-**

We have not found specific reports of economic impacts for *Balanus amphitrite* in North American waters. *B. amphitrite* is one of the most abundant fouling barnacles in warmer harbors of the U.S, however (Moore and Frue 1959; Carlton 1979), and is very likely a major contributor to fouling of ship and harbor structures. Literature searches (Biological Abstracts; Zoological Records) indicate that *B. amphitrite* is a frequent test organism for various types of anti-fouling agents and treatments. Hull fouling by barnacles and other organisms has costly impacts for shipping lines and navies, greatly increasing fuel costs, decreasing maneuverability, and fouling internal seawater piping. Barnacles also greatly contribute to fouling of navigational buoys and coastal power station intakes (Haderlie 1984).

Balanus amphitrite (Striped Barnacle), together with *B. eburneus* and *B. improvisus*, is a competitor in fouling communities in Beaufort, North Carolina. *Balanus* spp. however, despite their high recruitment rate, they were readily overgrown by other fouling organisms (Sutherland and Karlson, 1977). In Tampa Bay, *B. amphitrite* strongly affected the composition of the fouling community, mainly by creating additional structure for the recruitment of sedentary tube-building organisms. Removing the living barnacle organism from the shells did not affect abundances of these colonists, while adding simulated barnacle shells increased recruitment (Bros 1987).

Lepas pacifica*Lepas pacifica* Henry 1940 (a gooseneck barnacle)**Synonyms-** *Lepas fascicularis pacifica* Ellis & Solander; *Lepas pectinata pacifica* Henry**Taxonomy Comments-****Native Range-** Northeast Pacific (Alaska to La Jolla California- Cheng and Lewin 1976; Kozloff 1996; Alaska Department of Fish and Game 1996; U.S. Museum of Natural History 2002)**Invaded Range-** None known**Invasion Date-** None known**1st Records-** None known**Probable Vector(s)****History of Spread-**

Lepas pacifica is a gooseneck barnacle native to the Northwest Pacific, from Alaska to California. To our knowledge, it has not been reported outside the Northwest Pacific. It commonly occurs on kelp (Cheng and Lewin 1976; Bernstein and Jung 1979; U.S. Museum of Natural History 2002) and has also been found on the skin of a Northern Elephant Seal (*Mirounga angustirostris*, Baldrige 1970) and on buoys (Woods Hole Oceanographic Institution 1953). These features give it considerable capacity for natural dispersal, but it seems to be limited to the cool waters of the West Coast.

Life History-**Maximum temperature, Adult-****Minimum temperature, Adult-****Optimum Adult survival range, temperature-****Maximum salinity, Adult-****Minimum salinity, Adult-****Optimum Adult survival range, salinity-****Maximum temperature, reproductive-****Minimum temperature, reproductive-****Optimum reproductive range, Temperature-****Maximum salinity, reproductive-****Minimum salinity, reproductive-****Optimum reproductive range, salinity-****Egg type-****Larval type-** Planktotrophic, nauplius → cypris (Barnes 1983)**Larval Duration-****Reproductive Season, Suisun Bay-****Size at settlement-****Adult Mobility type-****Life History Comments-**

Community Ecology-

Adult Horizontal Habitat type- Rocky, Coarse Woody Debris; Seaweed Beds; Buoys

Adult Vertical Habitat type- Epibenthic

Tidal Zone Range- Subtidal, Low Intertidal

Trophic Status- Suspension feeder

Food- Phytoplankton, Detritus

Competitors- Other Bivalves, Other Barnacles, Bryozoans

Predators- Crabs, Flatworms, Carnivorous Snails, Starfish

Impacts

Ecological Impacts-

Economic Impacts- Gooseneck barnacles (*Lepas* spp.) are sometimes abundant foulers of ship hulls (Woods Hole Oceanographic Institution 1953).

Impact Comments-

<i>Garveia franciscana</i>

Garveia franciscana Torrey 1902 (Rope Grass Hydroid)

Synonyms- (*Calyptospadix cerulea* Clarke 1882 = *Garveia cerulea* Calder 1971- see “Taxonomy Comments”) *Bimeria franciscana* Torrey 1902; *Bimeria monodi* Billard 1927; *Bimeria tunicata* Fraser 1943; *Perigonimus megas* Kinne 1956

Taxonomy Comments-

G. franciscana (Torrey 1902) may be synonymous with *G. cerulea*, which was described earlier by Clarke (1882), from Chesapeake Bay, as *Calyptospadix cerulea* and is reported to occur from the Chesapeake to New Brunswick. The chief morphological difference between the species is the number of eggs, only 1 in *G. franciscana*, 'several' to 'many' (~5-10 shown in drawings, Calder 1971; Clarke 1882). *G. cerulea* was reported to be restricted to polyhaline and euhaline salinities (Calder 1971), while *G. franciscana* is euryhaline. However, Calder later stated 'As for *Garveia cerulea* (Clarke's *Calyptospadix cerulea*), I am now pretty convinced that it is the same as *G. franciscana* (Calder personal communication 1997).

Genetic and rearing studies are needed to determine the relationship between the two forms. It is possible that the two forms are ecotypes. If they are conspecific, *G. cerulea* might be the correct name because of seniority, but new taxonomic rules may permit the more widely used name *G. franciscana* to prevail (Calder 1971; Calder 1997, personal communication).

Native Range- Unknown (Suggested: India/Indian Ocean; East Brisbane/Queensland/Brisbane River; “Australasia”) Deevey 1950; (Veervoort 1964; Carlton 1979; Cohen and Carlton 1995; Carlton 1997 personal communication); (If *G. cerulea* and *G. franciscana* are conspecific, a Northwest Atlantic origin for this species is possible- PF. However, even if the species are synonymous, Dale Calder and James T. Carlton (Personal communications, 1997) consider *G. franciscana*, to be a probable introduction to Chesapeake Bay).

Invaded Range- NW Atlantic (Venezuela/Lake Maracaibo to Fort Foster/NH/Great Bay, possibly to New Brunswick/Miramichi estuary (as *G. cerulea*), including TX/Corpus Christi Bay; SW Pacific (Pernambuco/Brazil/Rio Formosa Estuary); NE Pacific (Canal Zone/Panama/Pacific Ocean; CA/San Francisco Bay to the Sacramento-San Joaquin Delta); NE Atlantic (Netherlands to Germany/North Sea estuaries, Baltic Sea; Mediterranean (Venice/Italy/Lagoon of Venice, Adriatic Sea); Black Sea; Caspian Sea; SW Atlantic (Soelaba, Cape Cameroun, and Kwele Kwele Banc/Camerouns/Bight of Bonny; Victoria/Camerouns/Mabas Bay)

Invasion Date- 1901 (San Francisco Bay); 1943 (Louisiana Coast); 1940s (Freeport/TX/Gulf of Mexico)

1st Record- 1943 Louisiana Coast/Gulf of Mexico (Fraser 1943)

Probable Vector(s) Fouling

History of Spread-

Garveia franciscana (Rope Grass Hydroid) was first described from San Francisco Bay (as *Bimeria franciscana*; Torrey 1902) but its highly disjunct world distribution [Black-Azov Seas, India, Australia, San Francisco Bay, Atlantic-Gulf of Mexico (Great Bay New Hampshire to Brazil), Europe, West Africa] (Deevey 1950; Simkina 1963; Vervoort 1964) strongly suggests that it is introduced over much of its range. Carlton (1979) suggested an Indo-Pacific origin, but Calder (1997, personal communication) speculated that *G. franciscana* may have originated from the 'Sarmatic' region (Caspian-Black Sea), as several other widespread invading hydrozoans have. *Garveia* spp. were not reported from the Black Sea by Naumov (1969), and *G. franciscana* appear to have invaded the Sea of Azov around 1960 (Simkina 1963). The oldest verified European record seems to be from the Netherlands in 1922 (Vervoort 1964). (Dutch and Russian records were first reported under the name '*Perigonimus megas*', and confusion with *Cordylophora caspia* may have delayed recognition of this species.) The first Mediterranean record, from the lagoon of Venice, was found in 1978 (Morri 1980). The occurrence of *Garveia franciscana* at both ends of the Panama Canal (U.S. Museum of Natural History 2002) suggests both its susceptibility to ship transport and its ability to tolerate low salinities (1-5 ppt, Simkina 1965; Thompson 1993)

In San Francisco Bay, *G. franciscana* was collected by Torrey in 1901 (Torrey 1902). Fraser (1937) reported it from "various scattered locations in each of the three sections of San Francisco Bay. Low tide to 7 fathoms." (Fraser 1937). In a recent survey, it was found in San Pablo Bay and Carquinez Straits (Cohen and Chapman 2005). It was not included in a listing of introduced species in the Sacramento-San Joaquin Delta (Light et al. 2005). In SERC's Fouling plate surveys, it was found at one site in the South Bay, San Leandro Marina (Ruiz et al. unpublished data).

In the Gulf of Mexico, *G. franciscana* was present by 1943 (as *Bimeria tunicata* Fraser 1943), and abundant by 1950 (Crowell and Darnell 1950; Deevey 1950; Fraser 1943). Deevey (1950) reported it from Corpus Christi, Freeport, and Galveston Bay. In SERC's fouling plate surveys, it was found in every Gulf Coast harbor sampled, including Tampa Bay, Pensacola Bay, Galveston Bay, and Corpus Christi Bay (Ruiz et al., unpublished data). It is also abundant on the Atlantic Coast from Jacksonville, Florida to Delaware Bay, and has been collected in the Providence River, Narragansett Bay, Rhode Island Great Bay, New Hampshire (Calder 1971; Maurer and Watling 1972; Calder 1976; MIT Sea Grant 2003; Ruiz et al. unpublished data).

A source of uncertainty regarding *G. franciscana*'s invasion in the Northwest Atlantic is the presence of the very closely related *G. cerulea*, which differs from *G. franciscana* principally in having multiple eggs, and may be conspecific. In this account, we shall treat them as separate species, *Garveia cerulea* was first described from Fort Wool, Hampton VA in 1882 (Clarke 1882). In Chesapeake Bay it appears to be confined to polyhaline waters [lower James R., Calder 1971; mouth of the Potomac, Fraser 1944]. Its range on the Atlantic coast is from Chesapeake Bay to the Miramichi estuary, New

Brunswick (collected 1918, Fraser 1944). *Garveia cerulea* is usually considered as a native northwest Atlantic form, but *G. cerulea* appeared to be a recent arrival at Woods Hole MA: 'Dr. Hargitt believes that this species has but recently established itself in the region' (Sumner et al. 1913).

Life History-

Maximum temperature, Adult- 35°C (Field observations, thermal effluent, Chesapeake Bay, Cory and Nauman 1969)

Minimum temperature, Adult- 0° (Based on observed distribution, Cory 1967; Calder 1971).

Optimum Adult survival range, temperature- 10-32°C

Maximum salinity, Adult- 35 (Experimental, 21 days survival, Crowell and Darnell 1955)

Minimum salinity, Adult- 1 ppt (Experimental, Crowell and Darnell 1955)

Optimum Adult survival range, salinity- 5-25 ppt (Simkina 1965)

Maximum temperature, reproductive- 34°C Experimental, asexual reproduction, Louisiana, Crowell and Darnell 1955; 30°, field observations, South Carolina, Calder 1992)

Minimum temperature, reproductive- (9 °C, Regression of hydranths, Louisiana, Crowell and Darnell 1955; field observations , South Carolina, Calder 1992)

Optimum reproductive range, Temperature- 15-32°C (Experimental, asexual reproduction, Crowell and Darnell 1955; Simkina 1965; 15-24, field observations, larval settlement, Simkina 1965)

Maximum salinity, reproductive- 25 ppt (Asexual reproduction, Simkina 1965)

Minimum salinity, reproductive- 5 ppt (Asexual reproduction, Crowell and Darnell 1955; Simkina 1965)

Optimum reproductive range, salinity- 10-15 ppt,(asexual reproduction,Crowell and Darnell 1955; Simkina 1965; 8-15ppt (sexual reproduction, Simkina 1965);

Egg type-Brooded (Calder 1971)

Larval type- Lecithotrophic, planula→ (Calder 1971; Simkina 1965)

Larval Duration- 1 day (Simkina 1965)

Reproductive Season, Gulf of Mexico- April-November Lake Ponchartrain, Louisiana, (asexual reproduction, Crowell and Darnell 1955)

Size at settlement-

Adult Mobility type- Sessile colonies

Life History Comments-

Garveia franciscana (Rope Grass Hydroid) lacks a medusa stage. Instead, sexual reproduction takes place in the gonophores, where planula larvae are produced (Calder 1971). This hydroid appears to have broad environmental tolerances though it seems most successful under conditions typical of large estuaries with extensive brackish-water regions. It is capable of surviving in tropical and temperate climates (Vervoort 1965).

Experimental and field studies generally confirm the eurythermal and euryhaline nature of this species. The temperature and salinity range for sexual reproduction is narrower (15-25°C; 8-15 ppt) than for asexual colony growth (Crowell and Darnell 1955; Simkina

1965). Some experiments have suggested that this species survives well at marine salinities (Crowell and Darnell 1955), while others report death of colonies, or diminished growth at marine salinities (Simkina 1965; Thompson 1993). These results may vary with the environmental history of the colonies, or whether experimental conditions include acclimation.

Community Ecology-

Adult Horizontal Habitat type- Coarse woody debris; Marinas and docks; Oyster reefs

Adult Vertical Habitat type- Epibenthic

Tidal Zone Range- Subtidal, Low Intertidal

Trophic Status- Suspension feeder

Food- Zooplankton; Epibenthic animals

Competitors- Other Hydroids; Bryozoans

Predators- Nudibranchs

Impacts

Ecological Impacts- Competition; Predation; Habitat Change; Food/Prey

Economic Impacts- Industry; Habitat Change; fisheries

Impact Comments-

Ecological Impacts:

Although *Garveia franciscana* (Rope Grass Hydroid) is an abundant and sometimes dominant part of the fouling community in estuaries from Delaware Bay to Venezuela, its ecological impacts have not been rigorously studied. If *G. franciscana* and *G. cerulea* are separate species, and exotic and native, respectively, interactions are likely. However, the taxonomy of the species is unresolved, and the relative distribution and interactions of the forms is unknown.

Competition - *Garveia franciscana* and *Victorella pavidia* overgrew most other organisms on fouling panels at Calvert Cliffs MD in summer (Abbe 1987). Based on its abundance at many locations, *G. franciscana* appears to be seasonally competitive with native and other introduced fouling organisms in lower-salinity regions of estuaries (Crowell and Darnell 1955; Cory 1967; Calder 1976; Abbe 1987; Thompson 1993). *Garveia franciscana* overlaps spatially with *Cordylophora caspia*, although *C. caspia* ranges into lower salinities (Calder 1971; Cory 1967; Thompson 1993). It also co-occurs with *Victorella pavidia* (cryptogenic). *Victorella pavidia* and *G. franciscana* settle at the same time at Calvert Cliffs, but *G. franciscana* persists longer in summer (Abbe 1987).

Habitat Change - Growths of *Garveia franciscana* provide cover for numerous amphipods, mud crabs, and other organisms in the Patuxent River (Cory 1967) and James River (Thompson 1993). Crowell and Darnell (1955) suggest that growths of *G. franciscana* may provide important for shrimp, fishes, or their prey in Lake Ponchartrain.

Food - *Garveia franciscana* is fed on by nudibranchs, particularly *Tenellia* spp. (Abbe 1987; Cory 1967; Thompson 1993)..

Garveia franciscana has been reported to have major economic impacts in the Chesapeake Bay region, in Lake Maracaibo, Venezuela, and in the Sea of Azov (Russia-Ukraine), primarily as a fouling organism in powerplants. At two Chesapeake Bay powerplants, Chalk Point (Patuxent River) and Morgantown (Potomac River), the cost of biocides to control fouling dominated by *G. franciscana* was \$95,000 to \$180,000 per year in 1995-97 (Krueger 1997, personal communication). At the Surry Nuclear Power Plant on the lower James River, the weight of the hydroids caused breakdowns of the traveling screens and blockage of water flow in the plant's cooling system. Aggregates of hydroids blocked water flow in the main condensers, in the circulating water systems used for cooling during routine operation, and in the service water systems, which would be used in shutdown after an accident. 'Almost daily' cleaning was required during warm weather to keep water flowing through the service system. The operators of the plant instead undertook an extensive reconstruction of the cooling system and screens, which was intended to reduce fouling problems, with a projected cost of \$23.6 million, or \$2.1 million per year (Virginia Power 1992). Serious problems in industrial water systems have been reported in Ukraine on the Azov Sea (Simkina 1963) and in Venezuela, on Lake Maracaibo (deRincon and Morris 2003). Control of these organisms requires the use of biocides, most commonly chlorine, though ammonium hydroxide, hydrogen peroxide, sodium bromide-hypochlorite mixture, a surfactant mixture ("ClamTrol"), and chemically induced anoxia have been tested (Virginia Power 1992). Alternatively, fouling could be reduced by use of materials containing toxic metals such as zinc and copper (deRincon and Morris 2003), but with possible effects on water quality and desirable organisms.

Fisheries- Fouling by *Garveia franciscana* has been a major problem on fishing gear, including crab pots and oyster trays (Andrews 1973).

Habitat Change- *Garveia franciscana* probably benefits commercial and sport fisheries by providing habitat for juvenile and bait fishes, shrimps, crabs, and other motile organisms (Crowell and Darnell 1955; Thompson 1993).

<i>Turritopsis "nutricula"</i>

Turritopsis "nutricula" McCrady 1857 (hydroid and medusa)

Synonyms-

Turritopsis nutricula McCrady 1857

Tubiclava fructicosa Hilgendorf 1898

Turritopsis pacifica Maas 1988

Taxonomy Comments-

Native Range- NW Atlantic-Type locality Charleston SC (Schuchert 2004), range Massachusetts to Brazil (Calder 1971; Fraser 1946);

Invaded Range- Hawaii? (Coles et al. 1999); San Francisco Bay? (Fraser 1937; Carlton 1979); Galapagos Islands (Port Phillip Bay, Victoria, Australia? (Watson 1998)). (Some or all of these populations may be separate species within a species complex.

Invasion Date- 1925 (San Francisco Bay)

1st Record- Oakland/CA/San Francisco Bay

Probable Vector(s) Ballast Water; Fouling

History of Spread-

Turritopsis nutricula was described from Charleston, South Carolina, by McCrady, in 1857. Until recently, it was thought to be a cosmopolitan species, naturally dispersed by its long-lived medusa, and/or introduced possibly introduced by shipping to parts of its range (Fraser 1937; Fraser 1948; Russell 1953; Carlton 1979; Schuchert 1996; Watson 1998). Its presumed native range in the North Atlantic is from Vineyard Sound, Massachusetts to Brazil, including the Gulf of Mexico (Calder 1971; Deevey 1954; Schuchert 2004). Its range was believed to include the Northeast Atlantic, the Northeast Pacific (San Francisco Bay; Gulf of California, Galapagos Islands) (Fraser 1937; Fraser 1948; Calder et al. 2000); Northwest Pacific (China-Japan-Korea); and the Southwest Pacific (New Zealand) (Schuchert 1996).

Occurrences in San Francisco Bay, first reported in 1925 (Fraser 1937) were considered possibly introduced by Carlton (1979), although he also mentioned the possibility that they could represent part of a species complex. Introduced populations have also been reported from Pearl Harbor, Hawaii (Center for Aquatic Resource Studies 2006), Port Phillip Bay, Australia (Watson 1998), and New Zealand (Cranfield et al. 1998).

However, a number of populations previously identified as "*T. nutricula*" have been recently identified as separate species, including those in the North Sea (*T. polycirra*), Mediterranean (*T. dohrni*) and New Zealand (*T. rubra*) (Schuchert 2004). Consequently, there is uncertainty over the identity of Pacific populations of this hydrozoan. It is possible that *Turritopsis* introduced from Suisun Bay would be genetically distinct from the native forms.

Turritopsis 'nutricula' have sessile hydroid stages readily transported in hull fouling or with oysters, while the long-lived medusae are good candidates for ballast water transport. The medusae have the very unusual capability of regressing to the polyp stage, which is of great interest in studies of embryology and aging (Piraino et al. 1996), but also suggests an extra capacity for colonization.

Life History-

Maximum temperature, Adult-

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 34 ppt (Hydroids, Calder 1976)

Minimum salinity, Adult- 18 (Hydroids, medusae, Calder 1971; Calder 1976)

Optimum Adult survival range, salinity- 18-34 ppt

Maximum temperature, reproductive- 29°C (Calder 1992, field observations, South Carolina)

Minimum temperature, reproductive- 9°C (Calder 1992, field observations, South Carolina)

Optimum reproductive range, Temperature- 9-29°C

Maximum salinity, reproductive-

Minimum salinity, reproductive- 18 (Medusae; Calder 1971)

Optimum reproductive range, salinity-

Egg type- Planktonic (Schuchert 2004)

Larval type- Lecithotrophic (Calder 1971)

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Sessile epibenthos and planktonic medusae

Life History Comments

Hydrozoans of the *Turritopsis 'nutricula'* group settle as planulae and grow into sessile colonies, which produce medusa buds, and release medusae. However, members of the species complex are very unusual (apparently unique) in the ability to regress at any stage of medusa development, settle on surfaces, and develop into colonies of polyps. This reversal of development is the most extensive observed in any group of metazoans (Piraino et al. 1996). The extent to which this capability is distributed among the species complex is not clear- Piraino et al's observations were made on Mediterranean specimens, now identified as *T. dohrni* (Schuchert 2004).

Egg Type- Northwest Atlantic *T. nutricula* medusae release planktonic eggs, which develop into planulae, while Northeast Atlantic forms, now identified as *T. polycirrhata*, brood their eggs and release planula larvae (Schuchert 2004).

Community Ecology-

Adult Horizontal Habitat type- Rocky; Grass Beds; Oyster Beds; Coarse Woody Debris, Marinas-Docks; Vessel Hull

Adult Vertical Habitat type- Epibenthic; Planktonic

Tidal Zone Range- Subtidal, Low Intertidal

Trophic Status- Suspension feeder

Food; Zooplankton; mobile epibenthos

Competitors- Other fouling organisms; other medusae

Predators- - Snails, Nudibranchs, etc.

Impacts

Ecological Impacts- Hydroids and medusae of *Turritopsis* “*nutricula*” have been reported as possible introductions in California, Hawaii, Australia, and New Zealand, although some of these populations may represent native species of the “*nutricula*” complex.. In Australia (Watson 1998) and elsewhere, *Turritopsis* hydroids are a common part of the fouling community, particularly of docks and pilings..

Economic Impacts-

Impact Comments-

<i>Opercularella lacerata</i>

Opercularella lacerata (Johnston 1847) (hydroid)

Synonyms-

Campanularia lacerata Johnston 1847

Opercularella lacerata Nutting 1901

Taxonomy Comments-

Native Range- NE Atlantic-Type locality- St. Andrews and Berwick Bay, Scotland, Barents and White Seas to Mediterranean Sea (Schuchert 2001).

Crypogenic Range- NW Atlantic (Hudson Bay to Chesapeake Bay, Fraser 1944; Fraser 1946; Ruiz unpublished data); NE Pacific (Kachemak Bay, Alaska to Elkhorn Slough, Fraser 1946, California, Ruiz, unpublished data)

Invasion Date-**1st Record-****Probable Vector(s)****History of Spread-**

Opercularella lacerata was described from Scotland in 1847. In European waters, it ranges from the White and Barents Sea to the Mediterranean, and in the northwest Atlantic, from Greenland and Hudson Bay to Long Island and Chesapeake Bay (Fraser 1943; Fraser 1946; Schuchert, 2001). In the Northeast Pacific, Fraser (1943; 1946) collected it only from Departure Bay, Vancouver Island, British Columbia. It has subsequently been collected from Kachemak Bay, Alaska to Elkhorn Slough, California, and is also known from Japan and China (Fraser 1946; Lee-Anne Henry, in Hines and Ruiz 2001; deRivera et al. 2005). Reports of this species from the West Indies, Australia, Malaysia and Burma are uncertain, owing to taxonomic difficulties (Schuchert, 2001). The species' wide distribution is typical of boreal-arctic species, but it has been considered as a cryptogenic species in New England (Pederson et al. 2005), Elkhorn Slough (Wasson et al. 2005), and a possible introduction to Alaska (Lee-Anne Henry, in Hines and Ruiz 2001). Since this species lacks a medusa, hull fouling is the likeliest vector of transport.

Life History-

Maximum temperature, Adult-

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult-

Minimum salinity, Adult-

Optimum Adult survival range, salinity- poly-euhaline

Maximum temperature, reproductive-

Minimum temperature, reproductive-

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

**Minimum salinity, reproductive-
Optimum reproductive range, salinity-
Egg type-** Brooded (Schuchert 2001)
Larval type- Lecithotrophic (Schuchert 2001)
Larval Duration-
Reproductive Season, Suisun Bay-
Size at settlement-
Adult Mobility type- Sessile epibenthos

Life History Comments

Opercularella lacerata lacks a medusa stage, and broods its eggs in gonothecae, releasing lecithotrophic planula larvae (Schuchert, 2001).

Temperature & Salinity tolerances- Specific data on tolerances of *Opercularella lacerata* are not available, but its geographical distribution suggests that cool temperatures are optimal for this species. Its occurrence in the western Baltic (Schuchert, 2001) suggests some tolerance for reduced salinities.

Community Ecology-

Adult Horizontal Habitat type- Rocky; Grass Beds; Seaweed Beds; Coarse Woody Debris, Marinas-Docks; Vessel Hull

Adult Vertical Habitat type- Epibenthic

Tidal Zone Range- Subtidal, Low Intertidal

Trophic Status- Suspension feeder

Food; Zooplankton; mobile epibenthos

Competitors- Other fouling organisms; other medusae

Predators- - Snails, Nudibranchs, etc.

Impacts

Ecological Impacts- Impacts of *Opercularella lacerata* have not been reported.

Economic Impacts-

Impact Comments-

Clytia hemisphaerica*Clytia hemisphaerica* (Linnaeus 1767) (hydroid and medusa)**Synonyms-***Medusa hemisphaerica*- Gronovius 1960, Linnaeus 1767*Phialidium viridescens*- Leuckart 1856*Clytia johnstoni*- Hincks 1868*Phialidium variabile* Claus 1881*Clytia flavidula* Metshchnikoff 1886*Phialidium hemisphaericum* Mayer 1910*Clytia hemisphaerica* Cornelius 1995**Taxonomy Comments-**

The medusa was named and classified long before the hydroid, and the two forms were not officially given the same scientific name until 1995 (Cornelius 1995).

Native Range- NE Atlantic?-Type locality-Belgium, Barents and White Seas to Mediterranean Sea (Schuchert 2001).

Crypogenic Range- “polyp nearly cosmopolitan in temperate waters of all oceans” (Schuchert 2001). This species has been listed as a cryptogenic species in New England (Pederson et al. 2005), and in San Francisco Bay (as the whole genus *Clytia*, Cohen and Carlton 1995).

Introduced Range- . *Clytia hemisphaerica* has been listed as an introduced species in Port Philip Bay, Australia (Watson 1998) and in Hawaii (Coles et al. 1999).

Invasion Date-**1st Record-****Probable Vector(s)-****History of Spread-**

Clytia hemisphaerica is a hydrozoan with a worldwide range in temperate waters, both as an attached hydroid, and as a medusa. It was described from European waters in the 18th century and has been reported from 70°N in Norway to the Mediterranean, the equator, and South Africa (Russell 1953; Millard 1975). In Western Atlantic waters, it has been reported from the Canadian Arctic to Argentina, and was collected as early as 1872 in New England Waters (Verrill and Smith 1873; Genzano 1995). Its range includes the Gulf of Mexico (Galveston Bay, Defenbaugh 1973). In the Pacific, W.H. Dall collected the hydroid (as *Clytia johnstoni*) off Alaska in the late 19th century (1870s-1900, USNM 4446, 4452, 4459; US National Museum of Natural History 2006). It has been collected from Alaska to the Galapagos Islands (Fraser 1937; Fraser 1948), and in the Western Pacific from China, Japan, Australia, and New Zealand (Bouillon 1995; Watson 1998; Huang 2001). It was collected on fouling plates in nearly every North American port sampled (with the exception of Los Angeles-Long Beach) on the East, Gulf and West

Coasts, from Newfoundland to Corpus Christi and Dutch Harbor Alaska to San Diego Bay (Ruiz et al. unpublished data).

Occurrences of this hydrozoan in Hawaii and Australia have been treated as introductions (Watson 1998; Coles et al. 1999). It is likely that the range of *Clytia hemisphaerica* has been extended by shipping, because of the hydroid's frequent abundance in hull-fouling, and the medusa's potential for ballast water transport. However, this organism also has natural capabilities for long-range transport, as a medusa, and as a hydroid. Hydroids of *C. hemisphaerica* have been found attached to sea-turtles, fishes, floating logs, and mid-ocean masses of *Sargassum* (Cornelius 1982). It is also likely, given its range of climate and habitat, that "*Clytia hemisphaerica*" is a complex of several species. Russell (1953) suspected that least two species of this form existed in British waters, based on the morphology of medusae. Calder (1971) notes differences in morphology, growth habits, and an absence of reports of medusae in northwest Atlantic waters, compared to those in Europe. Consequently, *Clytia hemisphaerica* should probably be regarded as cryptogenic over most of its range.

Life History-

Maximum temperature, Adult- 30+ °C (Calder 1971)

Minimum temperature, Adult- -2 °C (Schuchert 2001)

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 35+, Southampton Water, England (Lucas et al. 1995)

Minimum salinity, Adult- 15 ppt, Southampton Water, England (Lucas et al. 1995); but oligohaline waters (0-5 ppt) in Chesapeake Bay (Calder 1971).

Optimum Adult survival range, salinity- meso-polyhaline

Maximum temperature, reproductive- 30°C (Calder 1992, field observations, South Carolina)

Minimum temperature, reproductive- 6°C (Calder 1992, field observations, South Carolina)

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity- 20-35 (Lucas et al. 1995)

Egg type- Planktonic (Schuchert 2001)

Larval type- Lecithotrophic (Schuchert 2001)

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Sessile epibenthos; Planktonic

Life History Comments

Clytia hemisphaerica has a sessile, asexually reproducing hydroid stage and a planktonic sexually reproducing medusa (Russell 1953).

Community Ecology-

Adult Horizontal Habitat type- Rocky; Grass Beds; Seaweed Beds; Coarse Woody Debris, Marinas-Docks; Vessel Hull

Adult Vertical Habitat type- Epibenthic; Planktonic

Tidal Zone Range- Subtidal, Low Intertidal

Trophic Status- Suspension feeder

Food; Zooplankton; mobile epibenthos

Competitors- Other fouling organisms; other medusae

Predators- - Snails, Nudibranchs, etc.

Impacts

Ecological Impacts-

Economic Impacts- *Clytia hemisphaerica* is a common component in fouling communities on ships, docks, and buoys (Woods Hole Oceanographic Institution 1953).

Impact Comments-

Clytia kincaidi*Clytia kincaidi* (Nutting 1899) (hydroid and possibly a medusa)**Synonyms-***Campanularia kincaidi* Nutting 1899*Laomedea kincaidi* Leloup 1935*Clytia kincaidi* Fraser 1937**Taxonomy Comments-**

The hydrozoan *Clytia kincaidi* was described (as *Campanularia kincaidi*) from Puget Sound, and later reported as (as *Laomedea kincaidi*) from the Caribbean (Leloup 1935). Its current reported range is from Alaska to the Galapagos (Hines and Ruiz 2000; Calder et al. 2003), and from Chesapeake Bay to the Caribbean (Calder 1971). It seems difficult to believe that one species could have such a disjunct distribution in such different climates. Calder notes, in a personal communication '.. its taxonomy is very poorly known, in spite of considerable advances since my 1971 report was done. I consider it a valid species, tho' the whole genus is a difficult one and in need of revision' (Calder 1997, personal communication).

Native Range- NE Pacific**Crypogenic Range-** NW Atlantic (Klein Bonaire and Bonaire, Caribbean to Chesapeake Bay) Leloup 1935; Calder 1971

Introduced Range-

Invasion Date-**1st Record-****Probable Vector(s)-****History of Spread-**

The hydroid *Clytia kincaidi* was described from Puget Sound by Nutting in 1899 (Nutting 1899), and subsequently reported from Vancouver Island (Leloup 1935). It was found in Prince William Sound and Kachemak Bays (Hines and Ruiz 2000; Hines and Ruiz 2001). On the Pacific coast, it was seen on SERC fouling plates in Kodiak, Kachemak Bay, Prince William Sound, Sitka, Ketchikan, Coos Bay, and Humboldt Bay (Ruiz et al., unpublished data). Calder et al. (2005) found it in the Galapagos Islands. We are not aware of previous records from San Francisco Bay.

The first Western Atlantic record was from the islands of Klein Bonaire and Bonaire in the Caribbean (Leloup 1935). [‘These hydrothecae correspond perfectly to the description and figure 2, plate IV, given by C. Nutting (1915).’] *Clytia kincaidi* was not reported from the Atlantic coast of North America by Fraser (1944). *Clytia kincaidi* was first found on the North American Atlantic Coast in Chesapeake Bay by Calder, during field surveys in 1968-1969 (Calder 1971; Calder 1972), and subsequently found to be common in SC (Calder 1976; Calder and Hester 1978). ‘I expect its distribution is more or less continuous from the Caribbean to Chesapeake Bay’ (Calder 1997). This hydroid was also identified from SERC fouling plates in Narragansett Bay, Rhode Island Bay (Ruiz et al., unpublished data). Hydroids identified as “*Clytia* aff. *kincaidi*” were collected on the

Caribbean coast of Panama by Calder and Kirkendale (2005). However, we are not aware of previous records from the Gulf of Mexico or Texas.

We consider *Clytia kincaidi* to be cryptogenic on the North American Atlantic coast. Calder notes that 'there is no way to know how long it may have been part of the fauna of the Chesapeake' (Calder 1997, personal communication). If it was introduced to Chesapeake Bay, the Caribbean seems the likeliest source. The taxonomic relationship between Atlantic and Pacific populations appears to be unresolved, though Calder considers the species a valid one (Calder 1997 personal communication). It is possible that the Atlantic and Pacific forms are separate species.

Life History-

Maximum temperature, Adult- 32 °C (South Carolina, Calder 1992)

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 34 ppt, (South Carolina, Calder 1976)

Minimum salinity, Adult- 4 ppt, (South Carolina, Calder 1976)

Optimum Adult survival range, salinity- meso-polyhaline

Maximum temperature, reproductive- 32 °C (South Carolina, Calder 1992)

Minimum temperature, reproductive- 10 °C (South Carolina, Calder 1992)

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity-

Egg type- Planktonic (Calder 1971)

Larval type- Lecithotrophic (Calder 1971)

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Sessile epibenthos; Planktonic?

Life History Comments

Clytia kincaidi has a sessile, asexually reproducing hydroid stage. It is suspected to have a planktonic sexually reproducing medusa, but the medusa stage has not been observed.

Community Ecology-

Adult Horizontal Habitat type- Rocky; Grass Beds; Seaweed Beds; Coarse Woody Debris, Oyster Reefs; Marinas-Docks

Adult Vertical Habitat type- Epibenthic; Planktonic

Tidal Zone Range- Subtidal, Low Intertidal

Trophic Status- Suspension feeder

Food; Zooplankton; mobile epibenthos

Competitors- Other fouling organisms; other medusae

Predators- - Snails, Nudibranchs, etc.

Impacts**Ecological Impacts-**

Economic Impacts- *Clytia kincaldi* is common on the Pacific coast (Hines and Ruiz 2000; (Hines and Ruiz 2001; Ruiz et al., unpublished data). In the Atlantic, it is common in South Carolina (Calder and Hester 1978), and probably also on other parts of the southeast United States coastline and the Caribbean (Calder 1997, personal communication). However, its importance as a fouling organism is not known in this region.

Impact Comments-

Cuspidella* sp.Cuspidella* sp. (Hydroids and Medusae)**Synonyms-***Cosmetira pilosa* Forbes 1848; *Thaumantias pilosa* Forbes 1848 = medusa of *Cuspidella grandis* Hincks 1869 (Hanson 1998)*Staurostoma mertensii* Haeckel 1879; *Staurophora mertensii* Brandt 1865 (= medusa of *C. humilis* Hincks 1866?) (Hanson 1998)*Laofoeina tenuis* G.O. Sars 1874; *L. vilaeveliviti* Hadzi 1917 (= medusa of *C. humilis* Hincks 1862?) (Hanson 1998)*Laeodicea undulata* (Forbes and Goodsir 1852) (=medusae of *C. costata*, Hincks 1869). (Hanson 1998)**Taxonomy Comments-**

At least 4 species of *Cuspidella* have been reported from North American waters (*C. grandis*, *C. humilis*, *C. mertensi*, *C. costata*; *C. procumbens*) Fraser 1946; Schuchert, 2001; Integrated Taxonomic Information System 2006). However, identification of species from the hydroid phase is extremely difficult. “However, it is now clear that this hydroid refers to a number of quite different hydrozoan species, all only distinctive in their medusa phase (comp. Cornelius 1995). Thus, most “*Cuspidella*”- like hydroids can only be identified if their full life-cycle is known.” (Schuchert, 2001). Several different genera names have been applied to medusae believed to be associated with these small (0.2-2 mm), indistinct hydroids. Assigning correct names to these organisms will require a combination of rearing experiments and molecular analyses.

Native Range-**Crypogenic Range-** NE Pacific; NW Pacific; Arctic; NW Atlantic; NE Atlantic; Red Sea; Indian Ocean

Introduced Range-

Invasion Date-**1st Record-****Probable Vector(s)-****History of Spread-**

Hydroids placed in the genus *Cuspidella* are widespread, although records seem to be most numerous from high northern latitudes. As noted in “Taxonomic comments”, the similar, nondescript hydroids assigned to this genus give rise to morphologically distinct medusae. In at least one case, two or more species and genera of medusae (*Laofoeina tenuis*; *Laeodicea undulata*) have been attributed to the same hydroid (*C. humilis*) (Hanson 1998). Consequently, *Cuspidella* spp. are best referred to as an unresolved species complex.

Most records of *Cuspidella* spp. hydroids on temperate coasts of North America refer either to *C. grandis* or *C. humilis* (Fraser 1937; Fraser 1944; Fraser 1946; Deevey 1950). We are not aware of previous reports of *Cuspidella* spp. from San Francisco Bay, but these hydroids are easily overlooked.

Cuspidella grandis has been reported from Kachemak Bay Alaska (Hines and Ruiz 2001) to Vancouver Island (Fraser 1946) in the Northeast Pacific, Commander Islands and Japan in the Northwest Pacific (Hines and Ruiz 2001), from Georges Banks to Georgia (Fraser 1946; U.S. National Museum of Natural History 2002), and from the Barents Sea to Portugal (Hanson 1998). It was found on SERC fouling plates only at Dutch Harbor and Kachemak Bay (Ruiz et al., unpublished data).

Cuspidella humilis is known from Kachemak Bay and Dutch Harbor, Alaska (Ruiz et al., unpublished data) to Colombia (Fraser 1946), from the Gulf of St. Lawrence (Calder 2003) to Beaufort, North Carolina, and Texas (Fraser 1946; Deevey 1950), and from Iceland and Spitzbergen to England (Hanson 1998), and possibly to the Mediterranean and Cape Verde Islands (Fraser 1946). It was found on SERC fouling plates *Cuspidella humilis* has also been reported from India (Venugopalan and Wagh 1986). Deevey (1950) reported this hydroid from Freeport, Texas. On SERC fouling plates, it was found from Dutch Harbor, Kachemak Bay and Prince William Sound, on the West Coast and Corpus Christi, Galveston Bay, and Pensacola Bays on the Gulf Coast.

“*Cuspidella*” hydroids possess the capacity for long-distance transport in fouling communities or in ballast water. However, the hydroids are small, and easily overlooked, and since they probably represent many undescribed species, anthropogenic invasions would be very difficult to detect.

Life History-

Maximum temperature, Adult-

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult-

Minimum salinity, Adult-

Optimum Adult survival range, salinity-

Maximum temperature, reproductive-

Minimum temperature, reproductive-

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity-

Egg type- Planktonic (Schuchert 2001)

Larval type- Lecithotrophic (Schuchert 2001)

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Sessile epibenthos; Planktonic?

Life History Comments

Cuspidella spp. have a sessile, asexually reproducing hydroid stage, and planktonic sexually reproducing medusae (Hanson 1998; Schuchert 2001).

Community Ecology-

Adult Horizontal Habitat type- Rocky; Marinas-Docks; “various substrates”

Adult Vertical Habitat type- Epibenthic; Planktonic

Tidal Zone Range- Subtidal,

Trophic Status- Suspension feeder

Food; Zooplankton; mobile epibenthos

Competitors- Other fouling organisms; other medusae

Predators- - Snails, Nudibranchs, etc.

Impacts

Ecological Impacts-

Economic Impacts-

Because of their small size, the occurrence and importance of “*Cuspidella*” spp. hydroids in fouling communities is not known. We are not aware of the abundance or ecological importance of the medusae.

Impact Comments-

***Obelia* spp**

***Obelia* spp.** Hydroids and Medusae

Obelia bidentata (Clarke 1875) (= *O. bicuspidata* Clarke 1875; *O. corona* Torrey 1904)

Obelia geniculata (Linnaeus 1758)

Obelia dichotoma (Linnaeus 1758)

Obelia longissima (Pallas 1766) (synonymized with *O. dichotoma* Cornelius 1975; recognized as a separate species, Cornelius 1995).

Synonyms-

Obelia bidentata (Clarke 1875) (= *O. bicuspidata* Clarke 1875; *O. corona* Torrey 1904)

Obelia longissima (Pallas 1766) (synonymized with *O. dichotoma* Cornelius 1975; recognized as a separate species, Cornelius 1995).

Taxonomy Comments-

At least 4 species of *Obelia* have been reported from the Northeast Pacific and San Francisco Bay (Carlton 1979; Cornelius 1975; Claudia Mills in Cohen et al. 1998; Hines and Ruiz 2001; Ruiz et al., unpublished data). The taxonomy of this genus is extremely difficult. For example, Cornelius (1975) synonymized *O. longissima* and *O. bidentata*, but separated them again, when studies of nematocysts and other morphological features showed differences between the two forms (Cornelius 1995). All of these species have numerous synonyms, and all have cosmopolitan distributions, covering wide ranges of latitude and habitat. It is likely that some or all of these species are actually species complexes (Claudia Mills, in Cohen et al. 1998). A molecular analysis of populations of *O. geniculata* suggests that populations in the North Atlantic (France, Massachusetts, New Brunswick), North Pacific (Japan), and South Pacific (New Zealand) each represent a cryptic species (Govindarajan et al. 2005).

Native Range-

Crypogenic Range- NE Pacific; NW Pacific; Arctic; NW Atlantic; NE Atlantic; Indian Ocean; SE Pacific; SW Pacific; SW Atlantic; SW Pacific

Introduced Range-**Invasion Date-****1st Record-****Probable Vector(s)-****History of Spread-**

Hydrozoans of the genus *Obelia* are very widespread in coastal environments, as hydroids in fouling communities and as medusae in plankton. At least 4 species (*O. bidentata*; *O. geniculata*; *O. longissima*; *O. dichotoma*) have apparently cosmopolitan distributions. Three of these species were described from European waters in the 18th century- one (*O. bidentata*) was described from North American waters (Long Island) in the 19th century (Cornelius 1975; Cornelius 1995). Each of these 4 species has been reported in several ocean basins, and it is likely that some or all of them constitute complexes of cryptic species (Claudia Mills in Cohen et al. 1998; Govindarajan et al. 2005).

Obelia bidentata, in the Pacific, has been reported from San Francisco Bay, Hawaii, Australia, Japan, and New Britain (Cornelius 1975). On SERC fouling plates, it was identified from Puget Sound and San Francisco Bay (Ruiz et al., unpublished data). In the Atlantic, it was found from Maine to Brazil, and the Netherlands to Ghana (Cornelius 1975). It was reported as common on the Texas coast (Deevey 1950; Defenbaugh 1973) and was found on SERC plates from Rhode Island to Corpus Christi (Ruiz et al., unpublished data).

Obelia dichotoma has been reported from Alaska to Ecuador, Japan and Australia in the Pacific, and from Quebec and Norway to the Caribbean and Ghana in the Atlantic (Fraser 1946, Deevey 1950; Cornelius 1975). On SERC fouling plates, it was found from Dutch Harbor, Alaska, to Long Beach, California (Ruiz et al., unpublished data). It has been frequently found in San Francisco Bay (Cohen and Carlton 1995), and has been collected in Galveston, Freeport, and Corpus Christi, Texas (Deevey 1950; Defenbaugh 1973; Ruiz et al. unpublished data).

Obelia geniculata has been reported to be widespread on the Pacific Coast of North America, from Peru to British Columbia and in the Atlantic from Hudson Bay to Trinidad, and from Norway and Iceland to South Africa (Fraser 1946; Cornelius 1975). Deevey (1950) reported it from Sabine Pass, Texas, but on SERC fouling plates, the only Atlantic records were from Newfoundland (Ruiz et al., unpublished data). Molecular analyses suggests that "*O. geniculata*" consists of several cryptic species (Govindarajan et al. 2005).

Obelia longissima has been reported from the from the Aleutians to Los Angeles, and in the Atlantic from Greenland and Labrador to Chesapeake Bay and Scotland, but with some scattered records in the tropics (Fraser 1946; Schuchert 2001). On SERC plates, it was identified from at sites from Dutch Harbor to San Diego, and Newfoundland to Corpus Christi (Ruiz et al., unpublished data).

Obelia spp. have been reported as likely invaders in Port Philip Bay, Australia (*O. dichotoma*- Watson 1998) and San Francisco Bay (*O. ?dichotoma*; *O. bidentata*) (Carlton 1979; Cohen and Carlton 1995). *Obelia dichotoma* was first reported from San Francisco Bay in 1899 (as *O. commisuralis*), while *O. bidentata* was first collected (as *O. bicuspidata*) in 1912 (Cohen and Carlton 1995). However, the taxonomic difficulty of the group and the existence of species complexes make it difficult to recognize *Obelia* spp. as definite invaders in the Northeast Pacific (Claudia Mills in Cohen et al. 1998). Mills instead treats *Obelia* spp. as cryptogenic in the region. SERC fouling plates in San Francisco Bay collected all four species of *Obelia* (Ruiz et al., unpublished data). All four of these species have also been identified in Texas (Deevey 1950; Defenbaugh 1973; Ruiz et al., unpublished data).

Obelia spp. have great potential for dispersal, both by natural and anthropogenic means. Medusae can be dispersed in plankton, while the hydroids can be rafted on floating logs and seaweed, and have also been found on swimming organisms such as sea turtles

(Cornelius 1975; Cornelius 1982). The hydroids are also very common in ship hull-fouling communities, while the medusae have been seen in ship's ballast water (Carlton 1979; Ruiz et al., unpublished data). However, the taxonomic difficulty of the group makes it difficult to identify introduced populations. Molecular analyses may clarify the taxonomy and biogeography of *Obelia* spp. (e.g. *O. geniculata*, Govindarajan et al. 2005).

Life History-

Maximum temperature, Adult- -2 ° (*O. longissima*, based on range Greenland-Iceland, Schuchert 2001)

Minimum temperature, Adult- 32+ °C (*O. bidentata*, South Carolina, field observations, Calder 1992)

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 34+ ppt (*O. bidentata*, South Carolina, field observations, Calder 1976)

Minimum salinity, Adult- 0.5 ppt (*O. bidentata*, South Carolina, field observations, Calder 1976)

Optimum Adult survival range, salinity- Poly-euhaline (18-35, Calder 1976)

Maximum temperature, reproductive-

Minimum temperature, reproductive- 10°C (*O. bidentata*, South Carolina, field observations, Calder 1976)

Optimum reproductive range, Temperature- 32+ °C (*O. bidentata*, South Carolina, field observations, Calder 1992)

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity- Poly-euhaline (18-35, Calder 1976)

Egg type- Planktonic (Schuchert 2001)

Larval type- Lecithotrophic (Schuchert 2001)

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Sessile epibenthos; Planktonic?

Life History Comments

Cuspidella spp. have a sessile, asexually reproducing hydroid stage, and planktonic sexually reproducing medusae (Cornelius 1975).

Community Ecology-

Adult Horizontal Habitat type- Rocky; Grass Beds; Seaweed Beds; Coarse Woody Debris; Marinas-Docks; Vessel Hulls

Adult Vertical Habitat type- Epibenthic; Planktonic

Tidal Zone Range- Subtidal,

Trophic Status- Suspension feeder

Food; Zooplankton; mobile epibenthos

Competitors- Other fouling organisms; other medusae

Predators- - Snails, Nudibranchs, etc.

Impacts

Ecological Impacts- *Obelia* spp. hydroids are frequently an abundant component of fouling communities, while *Obelia* medusae are very common in plankton. However, the taxonomic difficulty of this genus has precluded the determination of invasion status or impacts.

Economic Impacts- *Obelia* spp. are a common component of ship hull-fouling (Woods Hole Oceanographic Institution 1953; Millard 1959).

Impact Comments-

Erichthonius brasiliensis*Erichthonius brasiliensis* Dana 1852**Synonyms-** *Pyctilus brasiliensis* Dana 1852; *Erichthonius brasiliensis* Dana 1855**Taxonomy Comments-**

This genus and species (of the family Corophiidae) have long been problematic. Over 20 species have been described, but many of these have been synonymized by some authors, who reduced the genus to 7-8 species (Myers and McGrath, 1984). *Erichthonius brasiliensis* was described from Rio de Janeiro, Brazil, by Dana in 1852, and has been reported from many regions of the world's oceans, including the Northeast Atlantic (Myers and McGrath, 1984), the Southeast Atlantic (Robinson et al., 2005), the Northeast Pacific (San Francisco Bay, Southern California, Puget Sound, Carlton, 1979; Cohen et al. 2002), Hawaii (Coles et al., 1999); the Southeast Pacific (Thiel, 2002), the Northwest Pacific (China, Xiangiu 1994), and the Indian Ocean (Mauritius, Apadoo and Myers, 2004). Records from northern European coastlines were found to be misidentifications of *E. punctatus* (Myers and McGrath, 1984), and it is likely that some other identifications of *E. brasiliensis*, such as those from the Northeast Pacific (Carlton, 1979) also represent misidentifications of closely related sibling species. Careful taxonomic work, including molecular studies, will probably be needed to determine the true range of this species.

Native Range- Western Atlantic? (Cape Cod-Brazil) (Bousfield, 1973; Bousfield, US)**Invaded Range/Cryptogenic range-** Mediterranean Sea (Bellan-Santini et al. 1982); Northeast Pacific (San Francisco Bay- Stimpson 1856, cited by Carlton 1979; San Diego Bay to Ventura Harbor, Cohen et al. 2002; Cohen et al. 2005; Puget Sound, Lie 1968, Barnard 1969, cited by Carlton 1979), Hawaii (Coles et al. 1998); Southeast Pacific (Thiel, 2002); Northwest Pacific (China, Xiangiu, 1994); Indian Ocean (Mauritius, Apadoo and Myers, 2004).**Invasion Date-** 1856? (San Francisco) (Stimpson, 1856, cited by Carlton, 1979; 1932?, La Jolla, California (Coe and Allen, 1937, cited by Carlton, 1979).**1st Record-** San Francisco? (Stimpson 1856, cited by Carlton 1979; 1932?, La Jolla, California (Coe and Allen 1937, cited by Carlton 1979).**Probable Vector(s)** Fouling; Ballast Water**History of Spread-**

The gammarid amphipod *Erichthonius brasiliensis* was described from Rio de Janeiro, Brazil, by Dana in 1852 and has been widely reported around the world. It may be native to the Western Atlantic, where it ranges north to Cape Cod (Bousfield, 1973; Myers and McGrath, 1984). This species builds tubes on hydroids and bryozoans, and is a common component of fouling communities (Bousfield, 1973), and has been reported from ship hulls and floats (Woods Hole Oceanographic Institution, 1952). Consequently, it has great potential for ship transport. At the same time, it belongs to a taxonomically

difficult genus (see discussion above), so that the identities of some of the records are questionable. For example, this species was long misidentified in northern European waters (Myers and McGrath, 1984). Consequently, we regard this species as cryptogenic over much of its worldwide range, pending molecular analysis. This amphipod has been repeatedly reported from Southern California, and Tomales and Bodega Bays (Carlton, 1979; Cohen et al. 2002; Cohen et al. 2005), although there is some question about the identification (Southern California Association of Marine Invertebrate Taxonomists 1998). We are aware of only one very early record from San Francisco Bay (Stimpson, 1856, cited by Carlton, 1979). This species is known from Texas waters, including Corpus Christi Bay (Corpus Christi Bay National Estuary Program, 1996).

Life History-

Maximum temperature, Adult- 30+ C (Greece, Mediterranean Sea, Chintiroglou et al. 1994)

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 38 ppt (Greece, Mediterranean Sea, Chintiroglou et al. 1994)

Minimum salinity, Adult- 15 ppt (New England, Bousfield 1973)

Optimum Adult survival range, salinity- 18-35 ppt (Chesapeake Bay, Wass 1972)

Maximum temperature, reproductive- 30+ C

Minimum temperature, reproductive-

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity-

Egg type- Brooded

Larval type- Brooded

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Epibenthic; Micronekton; Tycho planktonic; Demersal

Life History Comments-

Community Ecology-

Adult Horizontal Habitat type- Marinas and Docks; Grass Bed; Seaweed Bed; Coarse Woody Debris, Vessel Hulls

Adult Vertical Habitat type- Epibenthic; Tycho planktonic; Demersal

Tidal Zone Range- Subtidal;

Trophic Status- Herbivore; Suspension Feeder

Food- Macroalgae; Detritus

Competitors- other corophiid amphipods

Predators-

Comments- *Erichthonius brasiliensis* is a tube-building, filter-feeding amphipod. It builds tubes of mud and mucous on bryozoans and hydroids (Bousfield 1979)

Impacts

Ecological Impacts-

Ecological impacts of invasions of *Erichthonius brasiliensis* have not been reported.

Economic Impacts- Gammarid amphipods are important food organisms for juvenile game and food-fish, and for their smaller prey species.

<i>Monocorophium acherusicum</i>

Monocorophium acherusicum Costa 1851

Synonyms- *Podocerus cylindricus* Say 1817?; *Andouinia acherusica* Costa 1851; *Corophium acherusicum* Costa 1857; *Corophium cylindricum?* Verrill and Smith 1873; *Monocorophium acherusicum* Bousfield and Hoover 1997

Taxonomy Comments- Bousfield and Hoover (1997) split the genus *Corophium* into 13 genera. This division follows long-recognized divisions within the former genus (e.g. Shoemaker, 1934; Crawford, 1937), which is now treated as a subfamily (Corophinae), by Bousfield and Hoover.

This species, described by Costa in 1851, may be a *nomen nudum* (inadequate original description). However Bousfield and Hoover (1997) consider that the name should continue to be used, under the International Committee on Zoological Nomenclature's 50-year rule.

Synonymy - Say (1818) described '*Podocerus cylindricus*' from Egg Harbor NJ. The original type material was lost, but Verrill and Smith (1873) assigned the name *Corophium cylindricum* to a common corophiid of southern New England, and this form was formally described by Holmes (1905). Subsequently, this name was very widely applied on the Atlantic Coast of the United States. However, it is not clear that Say's material was a member of the subfamily Corophiinae (Shoemaker, 1934). Shoemaker re-identified all available vouchered specimens of '*C. cylindricum*' as '*C. acherusicum*', but some of these amphipods may have been the very similar *M. insidiosum*, described by Crawford in 1937 (Bousfield and Hoover, 1997; Crawford, 1937; Shoemaker, 1947). Bousfield and Hoover (1997) treat '*Podocerus cylindricus*' and '*Corophium cylindricum*' as synonyms of *M. insidiosum*. Therefore, the identity of amphipods identified as '*Corophium cylindricum*' is uncertain. In recent Chesapeake collections, *M. acherusicum* greatly outnumbers *M. insidiosum*. Therefore, we have assumed that early records of '*C. cylindricum*' in Chesapeake Bay refer to *M. acherusicum*.

Native Range- North Atlantic?; Northeast Atlantic? (Bousfield and Hoover, 1997); Northwest Atlantic? Western Atlantic?(Shoemaker 1947; Chapman, 2000)

Invaded Range- Northeast Pacific: CA/San Francisco Bay (1912), now baywide into the Delta (Shoemaker 1947, Carlton 1979; Cohen and Carlton 1995; Light and Moyle 2005); Baja California/Mexico/Bahia de San Quintin (1960, Barnard 1964, cited by Carlton 1979); CA/San Diego Bay (1950, Barnard 1959, cited by Carlton 1979); CA/Los Angeles-Long Beach Harbors (Mohr and Leveque 1948, cited by Carlton 1979; Cohen et al. 2002); CA/Humboldt Bay (1971, Stout 1971, cited by Carlton 1979); OR/Coos Bay (1942, Barnard 1954, cited by Carlton 1979); WA/Puget Sound (1915, USNM specimen, Carlton 1979); Vancouver Island/British Columbia/Straits of Georgia (Shoemaker 1947); Hawaii (1943, Coles et al. 1998); Northwest Pacific (eastern shelf of Sakhalin Island/Russia/Sea of Japan (2002, Zvyagintsev 2003) to Hong Kong/China/South China Sea (Xiangiu 1994), earliest record 1955?, Fukuyama Harbor/Japan/Seto Inland Sea (1955, Onbe 1966); Indian Ocean Egypt/Suez Canal (Shoemaker 1947); [Dar Es

Salaam/Tanzania/Indian Ocean (Shoemaker 1947); Durban/South Africa/Indian Ocean (Shoemaker 1947); Western Australia/Swan River Estuary (Poore and Storey 1999); Bunbury/Western Australia/Pacific Ocean (Poore and Storey 1999); Southwest Pacific Port Jackson (Sydney)/New South Wales/Pacific Ocean (Chilton 1921, cited by Poore and Storey 1999); Port Phillip/Australia /Port Phillip Bay (1963, Fearn-Wannan 1968); Christchurch/New Zealand/Lyttelton Harbour (Hurley 1954)

Invasion Date- 1912 (San Francisco Bay); (1958, Texas, Gulf of Mexico- Corpus Christi Bay National Estuary Program 1996

1st Record- CA/San Francisco Bay (Carlton 1979); (Freeport/TX/Gulf of Mexico,)

Probable Vector(s) Ballast Water; Fouling Community; Oysters-Accidental

History of Spread-

Monocorophium acherusicum, an epifaunal tube-building amphipod, has been so widely dispersed by shipping that its original range is unknown. 'However, the eastern North Atlantic, from which it was originally described, seems the most probable source region' (Bousfield and Hoover, 1997). However, Chapman (2000) considers *M. acherusicum* to be native to the Northwest Atlantic, and introduced to the coast of Europe, based on a phylogeographic analysis. This amphipod was originally described from Italy by Costa in 1851 and was subsequently collected from southern Europe, the Atlantic coasts of France and Holland, and West Africa (Senegal) (Crawford, 1937). [It may have been described from the Atlantic Coast of the U.S. by Say in 1818 (Say 1818), but the identity of his '*Podocerus cylindricus*' is uncertain (Shoemaker, 1934; Bousfield and Hoover, 1997)]. By 1937, *Monocorophium acherusicum* had also been collected from the Suez Canal, East Africa, the Falkland Islands, Hong Kong, and New Zealand (Crawford, 1937; Shoemaker, 1934), and later from Australia (Fearn-Wannan, 1968); Hawaii (Shoemaker, 1947) and Japan (Onbe, 1966). 'It is noteworthy that its present known distribution traces out some of the major shipping routes ...' (Hurley, 1954). This species has been collected from ship fouling in England (Crawford, 1937) and Hong Kong (Shoemaker, 1947), and is abundantly found on wharves, pilings, buoys, etc. (Crawford, 1937; Woods Hole Oceanographic Institution, 1952; Barnard, 1958). In the eastern Pacific, *M. acherusicum* was collected as early as 1905 in Yaquina Bay Oregon and now ranges from British Columbia to Baja California (Cohen and Carlton, 1995).

Monocorophium acherusicum was first collected in San Francisco Bay in 1912, and now ranges throughout the estuary, into the brackish waters of Suisun Bay and the Delta, where it has been collected as far upstream as Collinsville (Cohen and Carlton, 1995; Light and Moyle, 2005).

In the western Atlantic, the date of first record is uncertain because of taxonomic confusion. If Say's (1818) '*Podocerus cylindricus*' was identical with Smith and Verrill's '*Corophium cylindricum*' (Smith and Verrill, 1873), and most or all of these specimens were *M. acherusicum*, as asserted by Shoemaker (1934), then *M. acherusicum* may have been present on the Atlantic coast of North America (Little Egg Harbor, NJ) before 1818. Smith and Verrill's '*C. cylindricum*' may have been either *M. acherusicum* (Shoemaker

1934) or *M. insidiosum* (Bousfield and Hoover 1997). We have chosen 1873 as the date of first record in the Northwest Atlantic, since specimens of '*C. cylindricum*' from Smith and Verrill's (1873) Martha's Vineyard survey probably were deposited in the National Museum and identified by Shoemaker (1934) as *C. acherusicum*. However, some of these specimens may have been *M. insidiosum*, described by Crawford in 1937 (Shoemaker 1947). Most of the specimens of *M. acherusicum* examined by Shoemaker are no longer in the catalogs of the United States National Museum of Natural History, and so cannot be checked.

In the Gulf of Mexico, available records of *M. acherusicum* (FL/Suwanee River estuary (Mason et al. 1994); Freeport/TX/Gulf of Mexico (1958, United States National Museum of Natural History collections) ; TX/Corpus Christi Bay (Corpus Christi Bay National Estuary Program 1996); Bay Marchand Lease Area, 500 Ms N Of Platform /LA/Gulf of Mexico; FL/Crystal River (1978, United States National Museum of Natural History collections) are relatively recent, mostly from environmental surveys in the 1970s-1990s. This may reflect the extent of collections and research interest, rather than an actual range expansion. The range of this amphipod extends south to Brazil (Shoemaker, 1947; Valerio-Berardo and Miyagi, 2000), but we have no information on its occurrence in the Caribbean.

Life History-

Maximum temperature, Adult- 30°C (Onbe 1966, Field data, Japan)

Minimum temperature, Adult- -2 °C (Bousfield 1973, based on geographical range)

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 38 ppt (Field data, Mediterranean, Bellan-Santini et al. 1982)

Minimum salinity, Adult- 0 ppt (field data San Francisco Bay, Cohen and Carlton 1995); 6 ppt (Onbe 1966, Japan, experimental), 16 ppt (Field data, Chesapeake Bay, Feely and Wass 1971)

Optimum Adult survival range, salinity-

Maximum temperature, reproductive- 10°C (Onbe 1966, Field data, Japan)

Minimum temperature, reproductive- 30°C (Onbe 1966, Field data, Japan)

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity-

Egg type- Brooded

Larval type- Brooded

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Epibenthic; Micronekton; Tychoplanktonic; Demersal

Life History Comments-

Salinity- The minimum value for survival is based on a 48-hour survival experiment with animals from Fukuyama Harbor, Japan (Onbe, 1966). A longer experiment might have given values closer to those seen in the field. *Monocorophium acherusicum* ranges into

the uppermost mesohaline in recent settling plate data (16-21 ppt, Ruiz et al. unpublished). The maximum is based on occurrences in the Mediterranean, and Gulf of Mexico (Bellan-Santini et al. 1982; United States National Museum of Natural History collections), where prevailing salinities are high. This species probably tolerates even higher salinities.

M. acherusicum is a sedentary tube dweller much of the time, but does swim and occurs in the zooplankton, especially at night, or following disturbance by storms and river runoff (Grabe, 1980). 'Unlike other tubicolous animals, the amphipods are not obligatorily sessile, but move in and out of the tubes in search of food and to mate. Migration rates are high among the tubicolous amphipods, as evidenced by their early appearance on fresh blocks (experimental substrates)' (Barnard, 1958).

Community Ecology-

Adult Horizontal Habitat type- marinas and docks; rocky; grass beds; coarse woody debris, vessel hull; buoys

Adult Vertical Habitat type- Epibenthic; Micronekton; Tycho planktonic; Demersal

Tidal Zone Range- Subtidal

Trophic Status- Herbivore; Detritus Feeder; Suspension Feeder

Food- Macroalgae; Detritus

Competitors- Other corophiid amphipods, other fouling species

Predators- Fish, Birds

Impacts

Ecological Impacts-

Herbivory - Together with other tube-building, suspension-feeding amphipods, *M. acherusicum* could have a local effect on densities of phytoplankton and suspended detritus (Barnard, 1958).

Competition - Competition among Corophiid species in Chesapeake Bay has been suggested as a factor influencing their distributions (Feeley and Wass, 1971). However, this has not been tested experimentally.

Habitat Change - Tubes of corophiids represent a considerable modification of surfaces, which could affect other fouling taxa. Construction of tubes on vegetation could affect the plants' photosynthesis; masses of tubes on hard surfaces could provide habitat for meiofauna and smaller infauna.

Food/Prey - *Monocorophium acherusicum* is a frequent, and sometimes primary prey of juvenile fishes in Japan (Onbe 1966) and probably elsewhere.

Economic Impacts-

In Los Angeles Harbor, *Monocorophium acherusicum* dominated the biomass of the fouling community on pilings (Barnard, 1958). Barnard (1958) suggested that high densities of mat-forming fouling organisms such as corophiids (*M. acherusicum*; *M. insidosum*) and the polychaete *Polydora* spp. might deter the settlement of marine borers on wooden pilings. His suggestion of deliberately releasing small quantities of organic material near pilings, in order to encourage these suspension feeders has not been tested,

to our knowledge. Where it is abundant, *Monocorophium acherusicum* is probably an important prey of juvenile commercial fishes (Onbe, 1966).

Laticorophium baconi*Laticorophium baconi* (Shoemaker 1934)

Synonyms- *Corophium baconi* Shoemaker 1934; *Laticorophium baconi* Bousfield and Hoover 1997.

Taxonomy Comments- Bousfield and Hoover (1997) split the genus *Corophium* into 13 genera. This division follows long-recognized divisions within the former genus (e.g. Shoemaker, 1934; Crawford, 1937), which is now treated as a subfamily (Corophinae), by Bousfield and Hoover.

Native Range- Eastern Pacific? Paita/Peru/Pacific Ocean to Unimak Island/AK/Gulf of Alaska

Invaded Range- Oahu/Hawaii/Kaneohe Bay (1967, Coles et al. 1999), Northwest Pacific- Hong Kong/China/South China Sea (1985, Hirayama 1986); Southwest Pacific- New South Wales/Australia/Pacific Ocean (Australian Faunal Directory 2006); Northwest Atlantic- Florida/Indian River Lagoon (Nelson 1995)

Invasion Date- N/A?

1st Record- N/A

Probable Vector(s)

History of Spread- N/A

The amphipod *Laticorophium baconi* was described by Clarence Shoemaker from specimens collected in at Paita, Peru, in 1926. It has subsequently been collected in the Eastern Pacific from Unimak Island, Alaska to the Gulf of California, Mexico (Bousfield and Hoover, 1997; US National Museum of Natural History, 2002). This amphipod has also been reported from Hong Kong Harbor (Hirayama, 1986), at several locations in Oahu, Hawaii (1967, Coles et al. 1999), from southeastern Australia (Australian Faunal Directory, 2006), and from the Indian River Lagoon, Florida (Nelson, 1995). Detailed morphological descriptions are not available for the Florida and Australian records (Nelson, 1995; Australian Faunal Directory, 2006). This amphipod is present in Puget Sound and San Francisco Bay (Chapman, 2000). Bousfield and Hoover (1997) considered this species to be an Eastern Pacific native, and introduced to the Northwest Pacific and Hawaii, while Chapman (2000) listed it as introduced in the Eastern Pacific (without giving a native region). The majority of records are from the Northeast Pacific from Alaska to Mexico (Bousfield and Hoover, 1997; US National Museum of Natural History, 2002), suggesting this as part of the native region. We are unaware of records between Mexico and Peru, and do not know whether the Peruvian population is disjunct, or possibly introduced. The Japanese, Hawaiian, Australian, and Indian River Lagoon, Florida, populations appear to be introductions. The latter, if identified correctly, appears to be the only occurrence of this species from the Atlantic Ocean. We have found no records of *L. baconi* from the Gulf of Mexico.

We have found little ecological information on this species, but it has been collected from eelgrass beds in San Quintin Bay, Mexico (Quiroz-Vazquez et al. 2005), on fouling plates at La Jolla, California (Woods Hole Oceanographic Institution, 1952) and Hong Kong, and from seagrass beds, mud bottoms, and fouling communities in the Indian River Lagoon, Florida (Nelson, 1995). It is probably a tube-builder, like other members of the subfamily Corophiini. Ballast water and fouling communities are likely vectors of introduction.

Life History-

Maximum temperature, Adult-

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 39 (Quiroz-Vazquez et al. 2005)

Minimum salinity, Adult-

Optimum Adult survival range, salinity- poly-euhaline (Bousfield and Hoover, 1997)

Maximum temperature, reproductive-

Minimum temperature, reproductive-

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity- poly-euhaline (Bousfield and Hoover, 1997)

Egg type- Brooded

Larval type- Brooded

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Epibenthic; Micronekton; Tycho planktonic; Demersal

Life History Comments-

Temperature and salinity tolerances have not been determined experimentally for this species. It apparently prefers full marine salinities. We have not found records from brackish environments.

Community Ecology-

Adult Horizontal Habitat type- Grass Bed; Seaweed Bed; Rocky; Marina/Dock; Unstructured (Sand, Mud)

Adult Vertical Habitat type- Epibenthic; Micronekton; Tycho planktonic; Demersal

Tidal Zone Range- Subtidal

Trophic Status- Herbivore; Detritus Feeder; Suspension Feeder

Food- Macroalgae; Detritus

Competitors- other gammarid amphipods

Predators- Fish, birds

Impacts

Ecological Impacts- No ecological impacts have been reported from invasions of *Laticorophium baconi*.

<i>Stenothoe valida</i>

Stenothoe valida (Dana 1852)

Synonyms- *Stenothoe assimilis* (Chevreux 1908); *Stenothoe ornata* (Barnard 1930)

Native Range- Unknown [Cryptogenic in most temperate-tropical ocean regions, including Northwest Atlantic (Massachusetts to Colombia; US National Museum of Natural History 2002; MIT Sea Grant Center for Coastal Resources 2003); Gulf of Mexico (Florida Keys National Marine Sanctuary 2006), Caribbean Sea (Barbados, Cuba, Colombia; Lewis 1992; US National Museum of Natural History 2002); Southwest Atlantic (Brazil; Tararam et al. 2003); Northeast Atlantic (Germany, Belgium, England, Portugal, Mediterranean; Lincoln 1978; Bellan-Santini et al. 1993; Franke and Gutow 2003; Boaventura et al. 2006), Indian Ocean (South Africa); Northwest Pacific (Japan-Korea; Hirayama 1988; Kim and Kim 1991); Southwest Pacific (New South Wales, Australia: Australian Faunal Directory 2006); Southeast Pacific (Chile; Sepulveda et al. 2003)]

Invasion Range- Northeast Pacific (Humboldt Bay to San Quintin Bay, Baja California, Mexico)

Invasion Date- 1941 (San Francisco Bay);

1st Record- CA/San Francisco Bay ("all around the central Bay") (1941, Light 1941, as *Metopa* sp., re-identified by Chapman, Carlton 1979)

Probable Vector(s)- Ballast Water; Hull fouling

History of Spread-

The gammarid amphipod *Stenothoe valida* was described by Dana from Rio de Janeiro, Brazil in 1852. It appears to have a cosmopolitan range in temperate-tropical regions of the world's oceans. This amphipod is often found on or inside invertebrates of the fouling community, such as tunicates (Sepulveda et al. 2003), hydrozoan corals (Lewis, 1992), hydroids (Carlton, 1979), and on floating seaweeds such as *Sargassum* ssp. (Tararam et al. 2003; Franke and Gutow, 2003). The association with fouling invertebrates and seaweeds gives this amphipod a great potential for both natural and ship-assisted dispersal, making it very difficult to assign a native region to this amphipod. This form could represent a species complex, although Carlton notes that this possibility is "not as evident as among other taxa discussed here" (Carlton, 1979). Carlton considered *S. valida* to be possibly native to the Atlantic Ocean, and introduced to the Pacific.

Although *Stenothoe valida* has a cosmopolitan distribution, it appears to be a recent introduction to the Northeast Pacific. It has been reported from only five bays on the West Coast, San Quintin Bay, Mexico (1964), Newport Bay, California (1951), Los Angeles-Long Beach Harbor (1953), San Francisco Bay (1941) (Carlton, 1979), and Humboldt Bay (2000, Boyd et al. 2002). It is probably widespread in the Gulf of Mexico, although the only available record was in a species list for the Florida Keys (Florida Keys National Marine Sanctuary, 2006). This species has been found in fouling

of buoys (Woods Hole Oceanographic Institution, 1952) and hull-fouling of a sailing ship (Carlton and Hodder, 1995) and could also be transported in ballast water.

Life History-

Maximum temperature, Adult-

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult-

Minimum salinity, Adult-

Optimum Adult survival range, salinity- poly-eu

Maximum temperature, reproductive-

Minimum temperature, reproductive-

Optimum reproductive range, Temperature-

Maximum salinity, reproductive-

Minimum salinity, reproductive-

Optimum reproductive range, salinity- poly-eu

Egg type- Brooded

Larval type- Brooded

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Epibenthic; Micronekton; Tycho planktonic; Demersal; Commensal

Life History Comments- The geographical range of this species suggests that it tolerates warm-temperate to tropical coastal marine conditions, but its exact temperature and salinity requirements are unknown.

Community Ecology-

Adult Horizontal Habitat type- Salt/Brackish Marsh; Tidal Fresh Marsh; Grass Bed; Rocky; Marina/Dock; Unstructured (Sand, Mud); Coarse Woody Debris

Adult Vertical Habitat type- Epibenthic; Micronekton; Tycho planktonic; Demersal; commensal

Tidal Zone Range- Subtidal

Trophic Status- Carnivore

Food- algae; detritus; small invertebrates

Competitors- other small free-living amphipods

Predators- Fish; Hydroids; Anemones

Impacts

Unknown

Sinelobus* “stanfordi”**Sinelobus* “stanfordi” (Richardson 1901)**

Synonyms- *Tanais stanfordi* Richardson 1901; *Tanais philetaerus* Stebbing, 1904; *Tanais fluviatilis* Mañé-Garzón 1943; *Tanais sylviae*; Mañé-Garzón 1943; *Tanais herminiae* Mañé-Garzón 1943; *Tanais estuarius* Pillai, 1954; *Sinelobus stanfordi* (Sieg 1980)

Taxonomy Comments- This tanaid species, originally described by Richardson from the Galapagos Islands, was identified by Sieg (1980) as "*Sinelobus stanfordi*", a very widely distributed species or species complex (tropical-arctic). Cohen and Carlton (1995) have chosen to treat the California populations as an unidentified species, assuming the likelihood that "*S. stanfordi*" was a species complex and would eventually be split.

Native Range- Unknown [Cryptogenic Range- Northeast Pacific (1898, Clipperton Atoll, 1500 km SW of Mexico, U.S. National Museum of Natural History, 2002); Southeast Pacific Genovesa Island, Galapagos Island/Ecuador, Arcturus Lake (U.S. National Museum of Natural History 2002); Colombia/Pacific Ocean (Gutu and Ramos 1995); Northwest Pacific (Freshwater, Kurile Islands/Russia/Sea of Ohotsk (U.S. National Museum of Natural History 2002, Osaka/Honshu/Japan/Yodo River Estuary, Yamanishi et al. 1991) Miyagi Precture, Honshu/Japan/Nanakita River Estuary (Aikin and Kikuchi 2001); Southwest Pacific Queensland/Coral Sea (Australian Faunal Inventory 2006); Tarawera River, North Island/New Zealand/Flows into Bay of Plenty (Quinn and Hickey 1990)); Northwest Atlantic Wilmington/NC/Cape Fear River (Power et al. 2006); Jacksonville/FL/St. Johns River (Power et al. 2006); FL/Biscayne Bay (National Benthic Inventory 2006); FL/Florida Bay (National Benthic Inventory 2006); Florida Keys and Dry Tortugas/FL/Gulf of Mexico (National Benthic Inventory 2006); Quintana Roo/Mexico/Caribbean Sea (García-Madrigal et al. 2004); Jamaica/Caribbean Sea (Gardiner 1975); St. Lucia/Caribbean Sea (Gardiner 1975); Trinidad & Tobago/Caribbean Sea (Gardiner 1975); Gatun Locks/Panama Canal (1972, Jones and Rutzler 1975); Southwest Atlantic Brazil-Argentina (Gutu 1998; Orensanz et al. 2002; Rosa and Bemvenuti 2006); East Atlantic Port Harcourt, /Nigeria/Gulf of Guinea (1981, U.S. National Museum of Natural History 2002)

Invaded Range- Northeast Pacific-San Diego/CA/San Diego Bay (Cohen et al. 2002) to Vancouver area/British Columbia/Fraser River Estuary (1978, Levings and Rafi, 1979); Southwest Pacific (Cradoc/Tasmania/Huon estuary (Edgar et al. 1999)

Invasion Date- 1943 (San Francisco Bay)

1st Record- CA/San Pablo Bay (San Francisco Bay) (Miller 1968; Carlton 1979)

Probable Vector(s)- Fouling Community; Ballast Water; Oysters-Accidental

History of Spread-

Sinelobus “stanfordi” has been recorded from a cosmopolitan range of habitats and localities, including freshwater lakes, freshwater rivers; hypersaline lakes, maine

mudflats, marshes, mangroves, from cool temperate regions to the tropics. It may be a species complex. It was described from Galapagos Islands in 1901 and has been collected in both hemispheres, on both sides of the Atlantic and Pacific Ocean. This tanaid inhabits sediments but can also build networks of tubes of detritus and mucus in fouling communities, and has great potential for transport in ballast water, fouling, or with transplanted shellfish (Cohen and Carlton, 1995). It has also been collected from the freshwater Gatun Locks on the Panama Canal (Jones and Rutzler, 1975). We consider it cryptogenic over most of its worldwide range, including the Atlantic coast of the southeastern US (Power et al. 2006), the eastern Gulf of Mexico (National Benthic Inventory, 2006, and the Caribbean Sea (Gardiner, 1975; García-Madrigal et al. 2004). However, *S. "stanfordi"* has definitely introduced to the Northeast Pacific, and has been expanding its range. It was first collected on the West Coast in San Pablo Bay (San Francisco Bay) in 1943 (Miller, 1968; Carlton, 1979). In San Francisco Bay, it ranges from the more central portions of the Bay (San Pablo Bay; Lake Merritt) to the Delta (Cohen and Carlton, 1995; Light et al. 2005). Elsewhere on the West Coast, it has been collected in San Diego Bay (2000, Cohen et al. 2002), Elkhorn Slough (1979, Wasson et al. 2001), Humboldt Bay (Boyd et al. 2002; Wonham et al. 2005), Coos Bay, Oregon (1995, Carlton, unpublished data, Wonham et al. 2005), the Columbia River estuary (2003, Sytsma et al. 2004), Puget Sound (2000, Cohen et al. 2001), and the Fraser River, British Columbia (1978, Levings and Rafi, 1979).

Sinelobus "stanfordi" has not been reported from Texas. It has been found in the eastern Gulf of Mexico in Florida Bay and off the Florida Keys (Barry A. Vittor & Associates, Inc. 2000; National Benthic Inventory 2006).

Life History-

Maximum temperature, Adult-

Minimum temperature, Adult-

Optimum Adult survival range, temperature-

Maximum salinity, Adult- 0 (Gardiner 1975)

Minimum salinity, Adult- 45+ (Gardiner 1975)

Optimum Adult survival range, salinity- oligohaline-polyhaline (0.5-30 ppt, Levings and Rafi 1979; Cohen and Carlton 1995)

Maximum temperature, reproductive-

Minimum temperature, reproductive-

Optimum reproductive range, Temperature- warm-temperate-subtropical

Maximum salinity, reproductive- 0

Minimum salinity, reproductive- 45+ (Gardiner 1975)

Optimum reproductive range, salinity-

Egg type- Brooded

Larval type- Brooded

Larval Duration-

Reproductive Season, Suisun Bay-

Size at settlement-

Adult Mobility type- Epibenthic, mobile; Endobenthic, mobile, Tycho planktonic

Life History Comments-

Most tanaids are burrowing-or tube-constructing benthic organisms. They can inhabit sediments, where they can reach very high densities (Barnes, 1983). Adults swim occasionally, probably most frequently at night, and have been collected in plankton (García-Madrigal et al. 2004).

Community Ecology-

Adult Horizontal Habitat type- Non-tidal Freshwater; Salt/Brackish Marsh; Tidal Fresh Marsh; Unstructured (Sand, Mud); Seaweed Beds; Coral Reef; Marinas/Docks; Buoy

Adult Vertical Habitat type- Epibenthic, mobile

Tidal Zone Range- Subtidal

Trophic Status- Suspension feeder; Detritus feeder

Food- Phytoplankton; Detritus

Competitors-

Predators-

Impacts

Ecological Impacts- Ecological and economic impacts of *Sinelobus "stanfordi"* have not been studied. This species is sometimes present in high abundances, and could have effects on estuarine food webs, as a consumer of phytoplankton and detritus, as a food for benthic invertebrates and fishes, and as a habitat-altering burrower and tube-builder.