Decadal Assessment of Non-indigenous Marine Species in Southcentral Alaska: Kachemak Bay and Lower Cook Inlet (Part I)

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Executive Summary

Biological invasions by non-indigenous species (NIS) are a major force of change in coastal ecosystems around the world, with increasing ecological and economic impacts. While relatively few NIS are currently known in Alaska waters, this is increasing over time, due to human-mediated transfers of species associated with trade and vessel movement as well as environmental changes. A large portion of marine invasions to Alaska result from northward spread of NIS already established in California and other Pacific coast states. Although Alaska is at risk to many new invasions, this outcome is not inevitable. Coastwise spread along the Pacific coast is not possible for many of these NIS without human-mediated transfers, including especially species associated with vessels' hulls or ballast water. While management has advanced for ships' ballast water to reduce species transfers in waters of the United States, this has not been the case for biofouling organisms associated with vessel hulls and underwater surfaces. However, for both of these vectors, the risk of new NIS invasions in Alaska remains poorly resolved.

To assess the extent to which NIS are spreading northward along the Pacific coast of North America, we have implemented a decadal assessment across coastal sites from California to Alaska, repeating earlier surveys using standardized methods. Here, we report on our survey of Kachemak Bay, Alaska, that was conducted in summer and fall of 2025. At each of 10 sites, we deployed 10 panels, using a stratified random sampling design, where the panels are suspended from docks and serve as passive collectors for benthic invertebrate communities. For each site, we collected 10 replicate community samples, to characterize marine invertebrate species and NIS present. Five samples were analyzed morphological methods, and the other half were collected for future (pending) analyses by genetic methods. Here, we report on the results of morphological analyses for our survey.

We detected three NIS in Kachemak Bay in the 2025 survey. Of these two NIS were previously known to occur here, including the tunicate *Molgula citrina* and the amphipod *Caprella mutica*, whereas one NIS was a new record in Kachemak Bay and Alaska more broadly. This newly detected species, the syllid polychaete *Proceraea okadai*, is considered native to Japan and has introduced populations in California and Washington. This polychaete appears to be well established in Kachemak Bay, as it was detected at all 10 survey sites, occurring on 56% of the 50 panels analyzed across these sites. While it's not known when or how this species arrived in Kachemak Bay, northward dispersal by coastwise vessel traffic along the Pacific coast appears a likely source.

Overall, results from our recent surveys of Kachemak Bay (2025) and Prince William Sound (2023) suggest that new NIS are arriving and establishing populations in Alaska. We recommend sustained and repeated surveillance to further evaluate and inform actions to reduce invasion risks in this region of Alaska.

Acronyms and Abbreviations

^oC	Degrees Centigrade
LCL	Lower Confidence Limit
KM	Kilometer
M	Meter
N	North
NEMESIS	National Estuarine and Marine Exotic Species Information System (SERC)
NIS	Non-Indigenous Species
PWS	Prince William Sound
PWSRCAC	Prince William Sound Regional Citizens' Advisory Council
SC	Sample Coverage
SD	Standard Deviation
SE	Standard Error
SERC	Smithsonian Environmental Research Center
UCL	Upper Confidence Limit
W	West

Introduction and Rationale

Alaska's coasts are at risk to invasions by marine non-indigenous species (NIS), which can impact local communities and ecosystems. While relatively few NIS have invaded Alaska waters to date, several new NIS have been detected in recent years, due especially to northward range expansion.

A large number of NIS have established populations in coastal bays and estuaries along the Pacific coast of North America, with over 300 NIS known in California alone (Ruiz et al. 2015), and these are spreading northward (Ruiz et al. 2011). We have documented the recent detection of several NIS in Southeastern Alaska as well as Prince William Sound (PWS) (Fofonoff et al. 2018; Ruiz et al. 2024; Pappalardo et al. 2025). The majority of NIS in Alaska arrived by human-mediated transfer of species associated with vessels (ballast water and hull biofouling) and live trade (e.g., aquaculture, bait, fisheries). To date, most NIS detected in Alaska were previously known to the south and appear to have arrived by coastwise spread along the Pacific coast.

Our past work suggests that environmental conditions in Alaska (including Southcentral Alaska) are suitable for many of the NIS currently on the Pacific coast (Ruiz et al. 2024), and warming climate may enhance the opportunities for NIS colonization in Alaska in three ways. First, environmental species distribution models suggest that in Alaska, the probability of successful recruitment, growth, and reproduction (leading to established populations) may increase with warming temperatures. Second, global trade (e.g., polar shipping routes) is expected to grow with warming temperatures, increasing the potential for NIS transfers to Alaska waters (Miller et al. 2014). Third, in addition to shipping, a variety of other human activities are expected to expand as temperatures increase in the Arctic, expanding potential for species transfers and shoreline infrastructure (artificial habitat), which can both increase invasion opportunities (Ruiz et al. 2009; Ricciardi et al. 2017).

While it's clear that Alaska is exposed to the threat of NIS invasions, especially from secondary spread along the Pacific coast, it is also important to recognize that northward spread and invasion of Alaska is not inevitable. Most NIS on the Pacific U.S. coast and elsewhere occur in bays and estuaries, have limited dispersal ability, and would not spread coastwise (across bays) without human-mediated transfers. Thus, the extent of future invasions to Alaska waters depends upon the effectiveness of policy and management actions, which are advancing to prevent both initial invasions and secondary spread (e.g., Vessel Incidental Discharge Act (VIDA; Title IX of the Frank LoBiondo Coast Guard Authorization Act of 2018, U.S. Congress 2018; Federal Register 2024)).

Establishing a baseline to detect new NIS and evaluate changes over time are critical to assess the effectiveness of existing management actions to reduce invasion risks. The extent to which new NIS continue to arrive is a measure of efficacy for existing biosecurity, indicating whether additional steps are needed to further reduce NIS invasions. Such an approach provides critical feedback to inform adaptive management (Ruiz and Carlton

2003). To this end, we began conducting field-based surveys for detection of NIS at coastal sites throughout the United States, to evaluate changes in detection rates over time.

In Southcentral Alaska, both PWS and lower Cook Inlet are exposed to NIS transfers, due to different types of activities in each area. Each area has a different profile of vessel movement patterns and source regions, aquaculture activities, and coastal development. Species that arrive to one of these areas are likely to spread to the other, due to proximity and connectivity of these water bodies as well as vessel movements.

In 2024, we completed an extensive field-based survey of benthic marine invertebrate communities in PWS to evaluate the current status of NIS, using standardized morphological and molecular methods (Ruiz et al. 2024). This was part of a broadscale decadal survey, in bays from California to Alaska, to evaluate northward spread and the effectiveness of current biosecurity (management) efforts to prevent spread over time. We have focused on benthic communities, because this is where most of the NIS along western North America are known to occur (Ruiz et al. 2009). In addition, some separate field surveys of zooplankton communities were conducted in PWS between 2017 and 2021, to detect NIS using DNA metabarcoding.

These recent surveys of PWS detected several NIS that were not previously known to occur here. Some of these NIS were not reported previously for the Southcentral Alaska region, including PWS or Cook Inlet, and others were not known for Alaska at all. Most of these new NIS records were from one location or sample, such that it's not evident that the population is established. An alternative explanation for these detections is that propagules arrive, such as those associated with transient vessels, and organisms are indeed present but ephemeral, without establishing self-sustaining populations.

In this study, we conducted a field-based survey of benthic marine invertebrates for Kachemak Bay and lower Cook Inlet using the same methods as that for PWS (Ruiz et al. 2024) to provide a regional assessment for Southcentral Alaska and a comparison between the two systems. This is the first full-scale survey of Kachemak Bay NIS in more than 20 years. More broadly, as part of the Decadal Assessment (begun in 2020) of marine NIS across latitude on the Pacific coast, using identical methods, this survey will also facilitate direct comparisons with contemporary and identical surveys of bays in California, Washington, and Southeast Alaska. On both local and regional scales, these surveys aim to establish a baseline to evaluate invasion dynamics and biosecurity gaps across both temporal and spatial scales.

This report (Part I) focuses specifically on morphological analyses of the benthic marine invertebrate communities on hard substrate in Kachemak Bay. A second component (Part II) will conduct genetic analyses of these benthic invertebrate communities using DNA metabarcoding, pending additional support to conduct these analyses (see Methods for further detail). A third component (Part III) will conduct genetic analyses of zooplankton communities collected in Kachemak Bay, which is being funded separately by the Bureau of Ocean Energy Management. Together, these three components are intended to be parallel in design and compared to the recent surveys of PWS (Ruiz et al. 2024; Pappalardo et al. 2025) and other bays.

Methods

Following our standard protocols, developed over the past 25 years (Marraffini et al. 2017; Chang et al. 2018), we deployed PVC settlement panels, which serve as standardized habitats and passive collectors for benthic marine invertebrate communities. We have used these extensively through North and Central America for analysis and detection of NIS, allowing us to control for substrate type and history when evaluating patterns of community composition. Importantly, most marine NIS in waters of the United States are associated with anthropogenic hard substrate (Ruiz et al. 2009), making settlement panels an effective device for standardized measures of invasion dynamics across space and time. More specifically, we deployed 100 PVC settlement panels across 10 different sites (i.e., 10 per site) throughout Kachemak Bay, using a stratified random sampling design, such that panel locations were randomly located within each site. Specific locations and dates are indicated in Figure 1 and Table 1.

For each site, panels were suspended from existing infrastructure, including floating docks, marinas, and piers. Each panel was suspended 1 meter (m) below the water surface (Mean Lower Low Water, or low tide level), left for 3 months to allow for invertebrate recruitment and growth, and retrieved for analysis. Panels were deployed in June 2025 and retrieved for analysis in September 2025. The summer/warm season was targeted, as the warm temperatures, greater light, and higher food quality generally coincide with the timing of reproduction and greatest recruitment and growth for many invertebrates.

Salinity and temperature measures were taken at each site at 1m depth during panel deployment, and again upon retrieval, and a temperature data logger was also deployed at 1m depth at each site to measure hourly changes in temperature.

Upon retrieval, half of the panels were processed with morphological analyses, which are reported here. As planned in the scope of work, another half of the samples were preserved to process with genetic analyses (DNA metabarcoding), following the same design as the 2024 PWS survey and other bays in the Decadal Assessment, to allow direct comparisons across sites and latitude. While there is some overlap in species detected by morphological and genetic analyses, previous work has demonstrated that each analysis method detects unique species and NIS, such that the two methods are complementary and increase the total species pool detected when combined. (As noted in the Introduction, funding is pending for Part II of our study, and this is intended to be the focus of a separate report.)

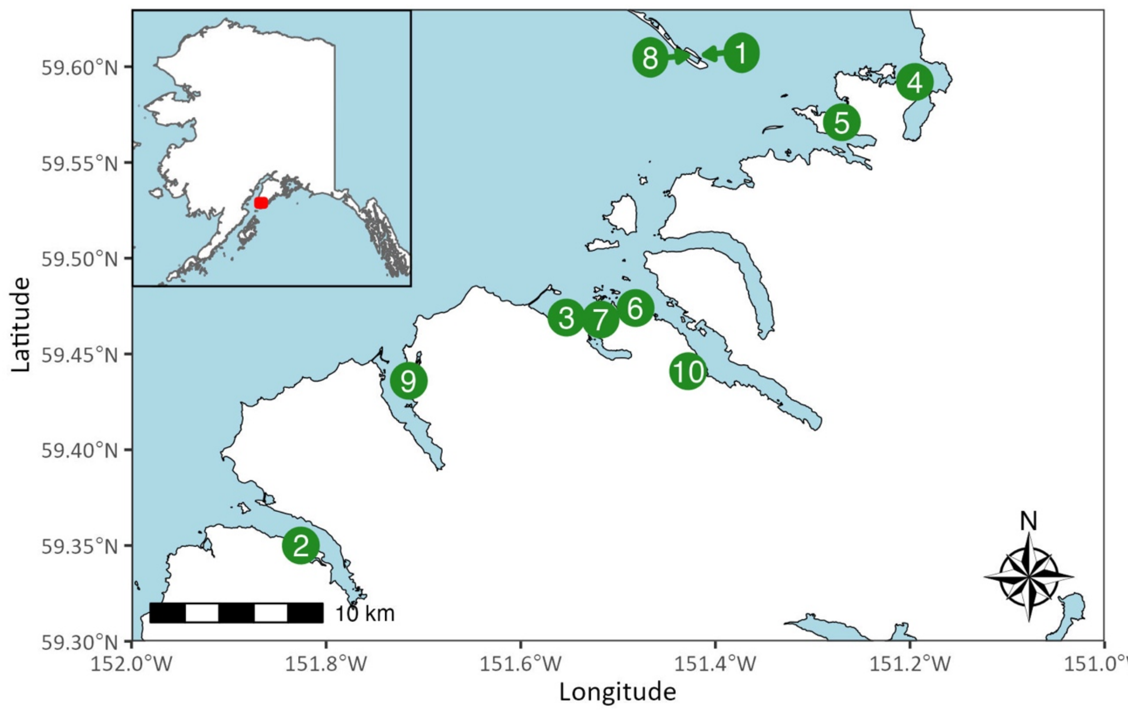

Figure 1: Map of hard substrate community sampling locations in Kachemak Bay (2025). Kachemak Bay's location is indicated by the red dot on the inset map of Alaska.

Table 1: Hard substrate community sampling locations in Kachemak Bay (2025).

Site No.	Site Name	Latitude (N)	Longitude (W)
1	Homer Spit Deep Water Dock	59.606	-151.415
2	Port Graham	59.350	-151.826
3	Kasitsna Bay Lab Dock	59.469	-151.553
4	Halibut Cove - Brenda D	59.592	-151.195
5	Peterson Bay Aquaculture Farm	59.571	-151.270
6	Tutka Bay Wilderness Lodge	59.474	-151.482
7	Bootlegger Cove	59.468	-151.518
8	Homer Spit Marina	59.606	-151.425
9	Seldovia Harbor	59.436	-151.715
10	Tutka Bay Hatchery	59.441	-151.428

Morphological Analyses

For each panel, we identified all marine invertebrate species present using our standardized workflow, which is designed to detect NIS among macroinvertebrate taxonomic groups, including especially annelids, arthropods, molluscs, and tunicates (i.e., groups for which NIS are most frequently detected and best resolved). Upon retrieval of the panels, all sessile and mobile macroinvertebrates were processed live under a dissecting microscope, generating morphological vouchers for species-level identification on each plate. These "field vouchers" were later identified to species (or lowest taxonomic unit), based upon close examination of morphological characteristics to confirm identifications using published taxonomic literature. A subset of these identifications was verified through additional consultation with outside taxonomic experts.

The morphological identifications of specimens produced a list of taxa identified to the lowest possible taxonomic level for each sample. For each taxon, we classified the current invasion status, based upon previous analyses, the literature, and using a synthesis of information in the National Exotic Marine and Estuarine Species Information System (NEMESIS; Fofonoff et al. 2018). Four categories were used for this classification: NIS, native, cryptogenic (of uncertain status, *sensu* Carlton (1996), and unresolved (where species-level identification could not be made because specimens were juveniles or in poor condition and did not possess diagnostic characteristics). As part of our workflow, any putative records of new species are examined closely, and compared to available databases and literature in consultation with taxonomic experts, to evaluate their invasion status.

Data Analyses

Using the morphological survey data, we compiled the number of NIS, native, cryptogenic, and unresolved taxa detected at each site and for the entire bay. We then constructed accumulation curves and calculated species richness estimators.

We conducted a standard series of statistical analyses to assess the completeness of our sampling efforts and estimate the number of NIS present. We used rarefaction to estimate the completeness of sampling for our level of sampling effort. This approach is combined with richness estimators calculated from our observations, to estimate the true (asymptotic) NIS richness detected in each habitat and to generate confidence intervals for detection. To estimate the number of NIS captured by our sampling methods, we used a relatively recently developed approach to species richness estimation that builds on traditional methods of rarefaction by combining rarefaction and extrapolation to make asymptotic estimates of richness along with quantifiable measures of sample completeness (Colwell et al. 2012, Chao et al. 2020).

Sample completeness, or sample coverage, is a key determinant of how close the estimated number of species is to the true number of species present (observed + undetected) in a sampled assemblage. The more complete a set of samples is estimated to be, the more likely it is that all species actually present have been detected (Chao et al. 2014, 2020, 2021).

Statistical analyses were carried out using R 4.2.3 (R Core Team 2023) and the R packages vegan 2.6-4 (Oksanen et al. 2022), and iNEXT.3D 1.0.1 (Hu and Chao 2023).

Results

1. Environmental Setting

Temperature and Salinity Conditions

Average temperatures during the three-month (June to September 2025) period of the survey varied from 10.9°C to 14.0°C, with considerable variation among and within sites (Figure 2; Table 2). The warmest site was Halibut Cove, and the coldest was the Homer Spit Deep Water Dock. The Kasitsna Bay lab had the highest average salinity, and the Tutka Bay Hatchery had the lowest (Table 2).

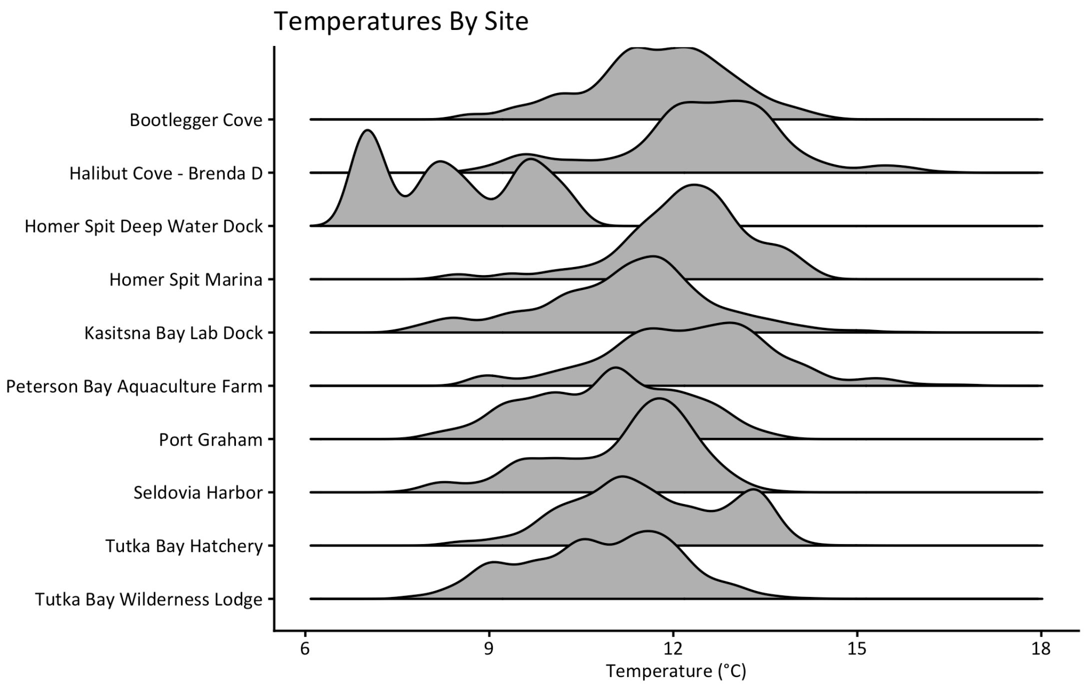

Figure 2: Distribution of temperatures recorded by loggers at 1m depth at each site during the survey period in Kachemak Bay in 2025.

Table 2: Environmental conditions at 1m depth at survey sites at Kachemak Bay in 2025. Temperatures (mean and standard deviation) are summarized from loggers recording at 1-hour intervals during the settlement panel deployment period, while salinity values are averaged from spot samples at 1m depth taken at panel deployment and again upon retrieval.

Site	Mean Salinity	Mean Temperature (°C)	SD Temperature
Homer Spit Deep Water Dock	32.0	8.4	1.2
Port Graham	32.8	10.9	1.2
Kasitsna Bay Lab Dock	33.0	11.2	1.4
Halibut Cove - Brenda D	29.6	12.4	1.4
Peterson Bay Aquaculture Farm	29.0	12.3	1.4
Tutka Bay Wilderness Lodge	32.6	10.8	1.2
Bootlegger Cove	31.5	11.8	1.1
Homer Spit Marina	30.3	12.2	1.1
Seldovia Harbor	32.0	11.2	1.2
Tutka Bay Hatchery	22.5	11.7	1.3

2. NIS Detection and New Records in Kachemak Bay

Species Detected by Invasion Status

We detected and identified a total of 158 unique taxa in the 2025 survey of Kachemak Bay, including approximately 50% of each mobile and sessile organisms. Among all taxonomic identifications for mobile and sessile invertebrates combined, 3 were classified as introduced (NIS), 49 as native, 13 as cryptogenic, and 93 as unresolved (Figure 3). The relative proportion of invasion status categories was similar for mobile versus sessile invertebrates. The frequency of occurrence for each taxon per site is shown in Appendix 1.

We note that a large fraction of taxa is unresolved, in terms of species-level identification and therefore invasion status, as shown in Figure 3. This is not unusual to have many taxa left unresolved by morphological analyses alone, as many lack diagnostic characters due to age, size or condition of organisms; based on our previous studies in other bays, we expect the pending genetic analyses (Part II of this project) will address part of this taxonomic information gap.

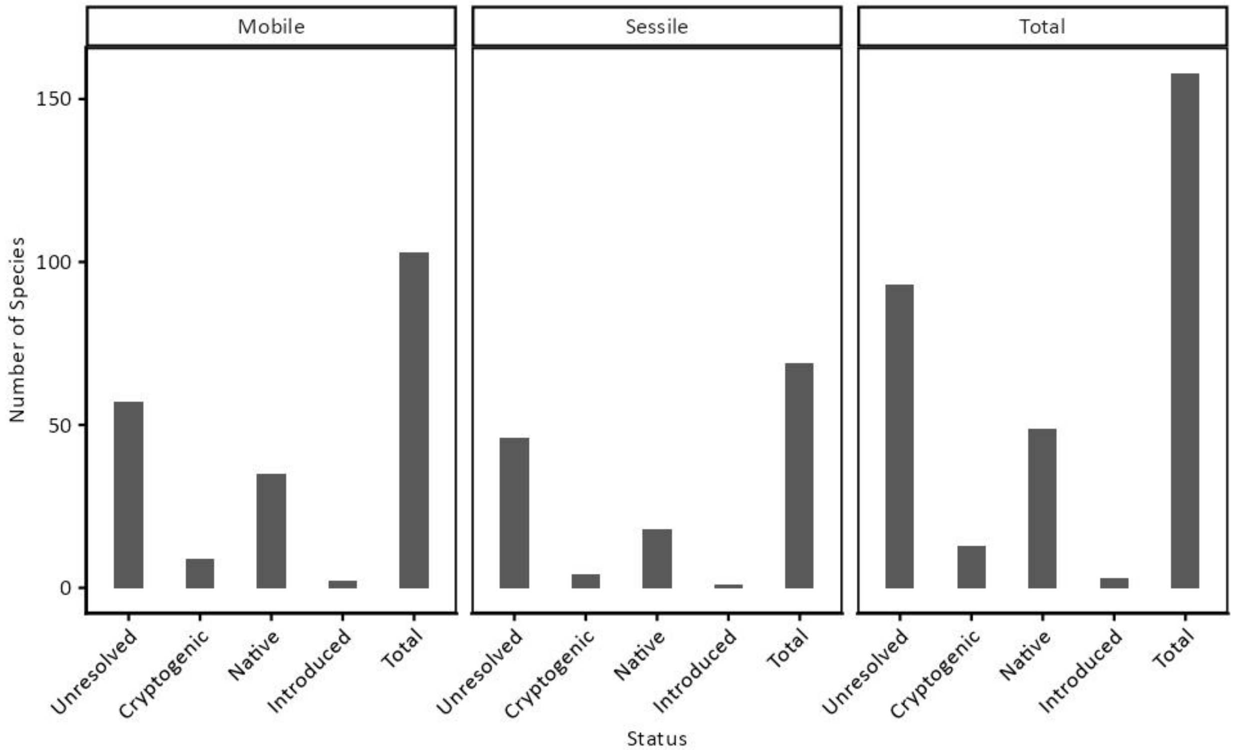

Figure 3: Number of unique species detected in Kachemak Bay hard substrate communities in 2025 by invasion status. Status was assigned based on literature and the NEMESIS database (Fofonoff et al. 2018).

Sampling Performance

Our statistical analyses indicate that this sampling program performed well in detecting and characterizing identifiable NIS in the Kachemak Bay hard substrate community. This is shown below in a series of figures depicting the detection of NIS using species accumulation curves and richness estimators calculated using R package vegan 2.6-4 (Oksanen et al. 2022).

Species accumulation curves (based on 1,000 random draws) show the rate at which new species are found in the surveyed area with additional sampling, providing a way to assess the completeness of sampling. An asymptote is reached nearly immediately for NIS, indicating complete sampling of the NIS community (Figure 4). Species richness estimators are reported along with their respective standard errors. The estimators generally agreed with the asymptote in NIS richness in Figure 3, further indicating that this result is robust (Table 3).

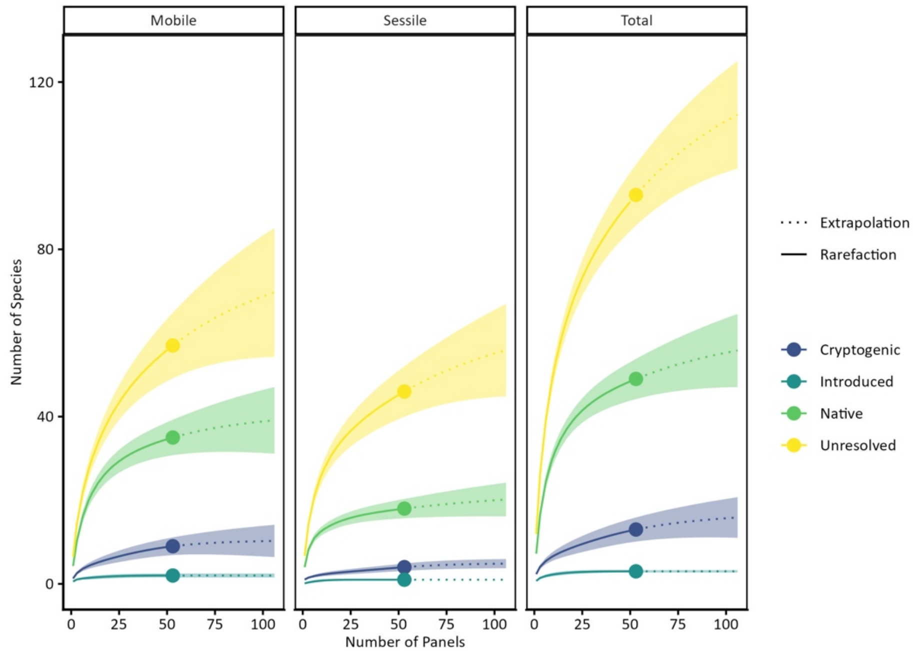

Figure 3: Species accumulation curves (based on 1,000 random draws) by invasion status for marine macroinvertebrates in Kachemak Bay hard substrate communities in 2025. Number of species detected as a function of panels for each invasion status. Invasion status is assigned based on literature and the NEMESIS database (Fofonoff et al., 2018). Here, a sample represents one settlement plate; up to 5 plates were analyzed from each of 10 sites in Kachemak Bay in 2025. Shading around each line represents ± 1 standard error (SE). Rarefied estimates (solid line) up to the number of observed samples (dot), beyond which estimates are extrapolated (dashed line) up to twice the size of the reference (observed) samples.

Table 3: Species richness and sample coverage estimators by invasion status for richness of marine macroinvertebrates in Kachemak Bay hard substrate communities (2025). Invasion status is designated based on literature and the NEMESIS database (Fofonoff et al. 2018). The sample coverage estimator (SC), observed number of species (Observed), richness estimator (Estimator), SE of the estimator, 95% lower confidence limit (LCL), and 95% upper confidence limit (UCL) are given.

Type	Status	Observed	Estimator	SE	LCL	UCL	SC
Mobile	Cryptogenic	9	10.47	3.87	2.89	18.05	95.81
Mobile	Introduced	2	2.00	0.20	1.61	2.39	100.00
Mobile	Native	35	41.01	17.43	6.85	75.17	96.98
Mobile	Unresolved	57	79.14	13.57	52.53	105.74	94.53
Mobile	Total	103	130.50	12.19	106.61	154.40	95.75
Sessile	Cryptogenic	4	4.98	0.42	4.15	5.81	96.50
Sessile	Introduced	1	1.00	0.00	1.00	1.00	100.00
Sessile	Native	18	22.42	5.90	10.85	33.98	98.60
Sessile	Unresolved	46	65.23	20.35	25.35	105.11	96.09
Sessile	Total	69	98.52	19.60	60.10	136.93	97.01
Total	Cryptogenic	13	17.09	6.30	4.75	29.43	96.06
Total	Introduced	3	3.00	0.27	2.46	3.54	100.00
Total	Native	49	61.26	14.16	33.50	89.03	97.43
Total	Unresolved	93	127.96	19.94	88.88	167.05	95.65
Total	Total	158	208.39	16.83	175.41	241.37	96.41

Overall, a very small percentage of the hard substrate community in Kachemak Bay was classified as Introduced (NIS), representing 1.9% of all taxa detected and identified in Figure 3. We detected no NIS at most sites (Figure 5) and mean NIS richness per plate was 0.72 ± 0.63 (mean ± 1 standard deviation (SD)) for all sites combined. Moreover, these NIS occupied a very small area, as measured by percent cover, compared to native taxa (Appendix 2).

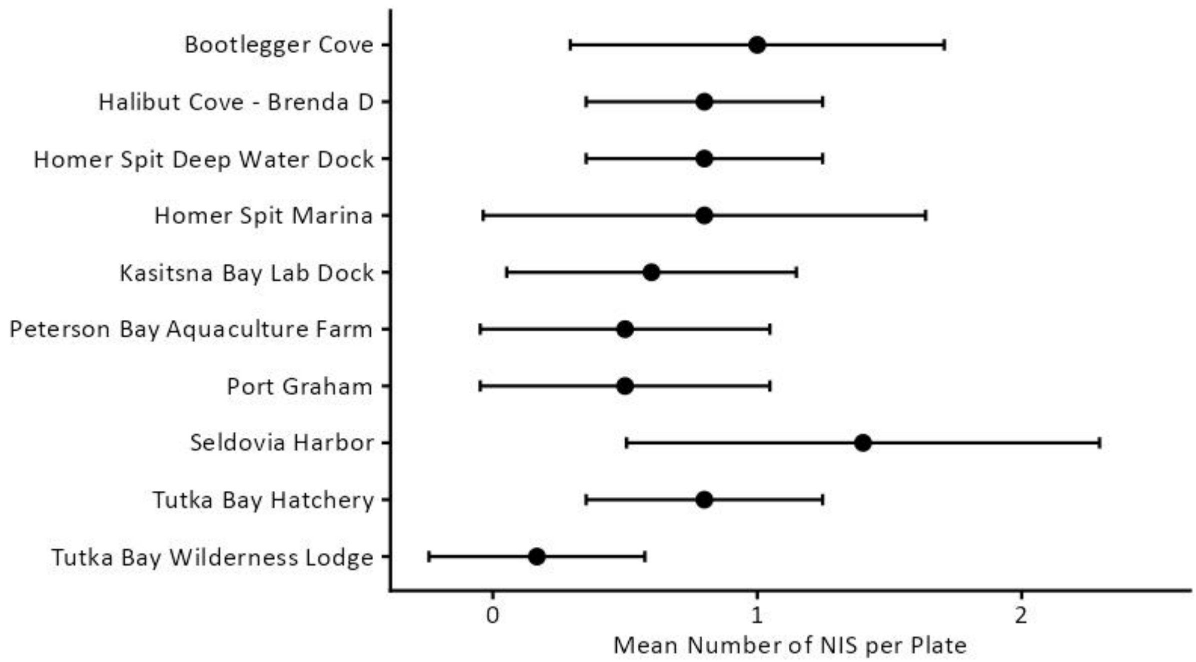

Figure 5: Mean number of NIS detected per plate averaged within sites in Kachemak Bay in 2025. Error bars equal ± 1 SD.

Introduced Species Detected in the Hard Substrate Community

The three introduced taxa identified in our survey of Kachemak Bay included the amphipod *Caprella mutica*, the tunicate *Molgula citrina*, and the syllid polychaete *Proceraea okadai*. Both *C. mutica* and *M. citrina* had previously been detected from the region. In contrast, we are not aware of any previous records of *P. okadai* detected in Alaska,

None of these species were found in our first full-scale survey of Kachemak Bay in 2000, and all appear to be established populations. The first records for *C. mutica* and *M. citrina* here were 2003 and 2008, respectively (Fofonoff et al. 2018; Ruiz et al. 2024), and these two species have persisted to the present time, although they did not occur in high prevalence in our current survey. In the 2025 surveys, the amphipod *Caprella mutica* was found at Homer Spit Marina and occurred on 3 panels, while the solitary tunicate *Molgula citrina* was detected on a total of 7 panels (Table 4), occurring at both Bootlegger Cove and Seldovia Harbor. None of these three sites where NIS were detected had unusual environmental conditions, as both temperature and salinity for the deployment period were well within the averages across Kachemak Bay (Table 2; Figure 2).

Although the polychaete *P. okadai* is a new detection for Alaska, it was found at all 10 sites and on a total of 28/50 (56%) of the panels surveyed. This high frequency of detection suggests there is a well-established population in Kachemak Bay.

Table 4: Introduced species detected in the 2025 Kachemak Bay hard substrate surveys. The number of panels per site with each species is presented.

Phylum	Group	Taxon	Number of Panels
Arthropoda	Caprellidae	*Caprella mutica*	3
Tunicata	Molgulidae	*Molgula citrina*	7
Annelida	Syllidae	*Proceraea okadai*	28

Discussion

Hundreds of marine NIS are known to be established on the Pacific coast of the United States, and this number declines from California to Alaska, creating a steep latitudinal gradient of declining species richness from south to north (Ruiz et al. 2011). While relatively few of these NIS occur at high latitudes, it is clear that these species are undergoing northward range expansion, due primarily to human-mediated dispersal associated with vessels, live trade, and other vectors.

Past work shows that environmental conditions of Alaska waters are currently suitable for colonization by many of these marine NIS, including those of PWS and lower Cook Inlet (Ruiz et al. 2024). Moreover, climate warming is expected to increase opportunities for invasions, due especially to increased vector activity (e.g., vessel arrivals) that can transfer NIS --- in the absence of further biosecurity measures to stem the tide of new invasions.

For marine invertebrates and algae, Fofonoff et al. (2018) document 19 marine NIS with established populations in Alaska. These were primarily northward range expansions, and the most recent detection was the European green crab (*Carcinus maenas*) in 2022. In addition, there have been many other NIS detected in Alaska waters, using either morphological or genetic analyses, although it's not evident in most cases whether these species have established self-sustaining populations (e.g., Jurgens et al. 2018; Ruiz et al., unpublished data). These include recent detections of NIS in PWS from our Decadal Assessment of benthic invertebrates (Ruiz et al. 2024), combining morphological and genetic analyses, as well as genetic analyses of zooplankton communities (Geller et al. 2013; Pappalardo et al. 2025).

In the most recent (2024) surveys of benthic marine invertebrates in PWS, three NIS were detected in our standardized panel surveys using morphological analyses, including the amphipods *Monocorophium acherusicum* and *Caprella mutica* as well as the bryozoan *Schizoporella japonica.* The latter two were also detected by genetic analyses. Of these, *M.*

acherusicum was a first record for PWS that was detected on one panel and is not known from Cook Inlet or the broader region of Southcentral Alaska; in contrast, the other two have been previously reported in the region, but *C. mutica* had not been reported previously from PWS. It is noteworthy that *M. acherusicum* was not detected in genetic analyses of our panels for PWS but was found in genetic analyses of zooplankton samples from PWS, again occurring in one sample, along with several other probable NIS (Pappalardo et al. 2025). It is also worth noting that several of the species detected in zooplankton samples have adult forms (e.g., amphipods, barnacles, polychaetes) that occur in benthic habitats. Importantly, for all the new records in PWS, it is not clear whether these represent established populations or may be transient organisms (or in the case of genetic analyses, DNA) released occasionally by arriving vessels or another vector.

In this context, the current study of Kachemak Bay provides an important assessment of whether these NIS are detected more broadly (beyond PWS), to test whether they may be established in the region, and whether additional novel NIS may be found in lower Cook Inlet, which also has unique vessel traffic and vector activity. In short, this contributes to a regional assessment of invasion dynamics for Southcentral Alaska.

Our 2025 benthic invertebrate survey of Kachemak Bay detected three NIS by morphological analyses. While two of the species (the amphipod *C. mutica* and the tunicate *M. citrina*) were previously known to occur here, the syllid polychaete *Proceraea okadai* is a new record for both Kachemak Bay and Alaska more broadly. This species is native to Japan and has introduced populations in San Francisco Bay, California, and Puget Sound, Washington (Fofonoff et al. 2018). This distribution suggests the likely northward spread along the Pacific coast to Alaska. The species is known to occur in benthic communities and also has reproductive life stages in the water column, indicating its arrival to Alaska may be associated with biofouling or ballast water of vessels. The extent of its current distribution in Alaska is unknown, and its potential ecological effects on marine communities has not been evaluated to date.

Our morphological analyses provided no evidence that the novel species detected recently in PWS, albeit relatively rare in frequency, are found in Kachemak Bay. Pending genetic analyses (underway) for both benthic invertebrate and zooplankton samples collected in 2025 will provide further insight about the current status of these and other potential NIS in Kachemak Bay and Cook Inlet, especially since several previous detections at many sites in past surveys along the Pacific coast were from genetic analyses, which often detect additional species beyond morphological analyses alone.

More broadly, this study helps establish an important baseline to evaluate changes in community composition and invasion dynamics in Alaska waters over time, in response to both changing human activity as well as climate in nearshore coastal habitats, which are especially vulnerable to both forces. In particular, it is expected that Alaska will be increasingly exposed to rapid changes in sea temperature, which in turn is likely to drive changes in vessel movement and shoreline development, increasing delivery of organisms and exposure to invasions (Ricciardi et al. 2017). A major component of this is expected to result in opening of the Northwest Passage as a major shipping route in the future, increasing vessel traffic to Alaska and expanding infrastructure of ports, such as Nome. In addition, such climate change may increase susceptibility of Alaska to invasions.

This baseline serves not only to document invasion dynamics but also to inform critical marine biosecurity management and policy decisions. While expected changes in climate and human activity can increase invasion risks in Alaska, it's evident that relatively few marine NIS are established currently here compared to many global regions. It also is evident that most NIS will not arrive without human transfer, due to their life histories and limited dispersal capability. Importantly, there is no doubt that management of ballast water over the past several decades has decreased the likelihood of invasions to Alaska, however residual risk still remains and is not well understood (National Research Council 2011; Outinen et al. 2024). Moreover, despite existing hull husbandry practices, there are not currently standards or regulations in place to limit biofouling on vessels arriving to Alaska, and biofouling remains a major vector for NIS transfers throughout the world (Bailey et al. 2020; Davidson et al. 2020). Thus, evaluating invasion dynamics provides key data to assess gaps in prevention and which vector(s) are contributing to new NIS arrivals, identifying where further adjustments to prevention strategies would be most effective.

Recommendations

We recommend repeating these standardized surveys and analyses at regular intervals, including both benthic invertebrate and zooplankton communities, to evaluate long-term changes in biological communities of Kachemak Bay. The resulting data are critical to both evaluate invasion dynamics and inform effective biosecurity measures to prevent new incursions of NIS. In addition, these data also serve to assess broad-scale community changes through time in coastal bays and estuaries, in response to climate change or other pulse disturbance events, resulting from environmental changes (e.g., temperature, rainfall, heatwaves, invasions, and plankton blooms) or human activities (e.g., oil spills).

As a minimum, we recommend a survey frequency of every 5-10 years in both Kachemak Bay and PWS, given their strategic locations at the nexus of intensive shipping, fishing, recreation, and other human activities. This survey frequency would align with a broader decadal survey across Pacific coast sites, allowing comparisons from California to Alaska.

More frequent surveys provide higher temporal resolution and better statistical estimates of new invasions, reducing the lag-time between new incursions and their detection. To this end, the Smithsonian Environmental Research Center (SERC) has established several sentinel sites on the Pacific coast, Atlantic coast, Gulf coast, and Great Lakes of North America, with full-scale surveys (as conducted in the current study) every 1-3 years, to accelerate NIS detection and knowledge of invasion dynamics. Thus, in addition to decadal surveys, we suggest establishing one sentinel site in the region of Southcentral Alaska, located in either PWS or Kachemak Bay. This would have high value for this region, increasing NIS surveillance (to approximately 3-year intervals) and providing higher resolution baseline data to evaluate changes in invertebrate communities over time.

Independent of these standardized community-level surveys, there is also an important and ongoing role for watch programs to detect particular target species in Alaska, focusing on NIS that are easily recognizable and can have significant ecological impacts. Such species include the tunicates *Didemnum vexillum* and *Ciona* spp. as well as the crab *Carcinus maenas* (Fofonoff et al. 2018). The PlateWatch program targets these and other tunicates (https://platewatch.nisbase.org/pages/about) across sites in Alaska, including long-term and sustained measures in both PWS and Kachemak Bay. Importantly, the latter includes both Homer Spit Marina and Seldovia, where most NIS have been detected historically and in the current survey for Kachemak Bay. In addition, detection efforts for *C. maenas* are also ongoing in both PWS and Kachemak, including both public reporting (https://www.adfg.alaska.gov/index.cfm?adfg=invasiveprofiles.europeangreencrab_characteristics) and focused trapping programs.

Such watch programs are complementary to community-level surveys, and we recommend that both be sustained over time in Kachemak Bay and PWS. While community-level surveys provide a more comprehensive and robust assessment of invasion dynamics, they also require more effort per event than surveys for target species. In contrast, surveys for conspicuous target species can be conducted broadly and frequently by a wide range of participants with or without taxonomic expertise, and this approach can provide rapid detection of selected species, which often include NIS with known impacts. Moreover, watch programs serve to increase public awareness and engagement, which can help reduce NIS transfers and invasions. In summary, sustained surveys and watch programs each have high and complementary value for this region, and both play vital roles in improving marine biosecurity.

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Appendix 1: Taxa Identified in Survey

Species detected in the 2025 Kachemak Bay hard substrate survey. The number of plates per site with each species is presented, along with invasion status and the total across all sites.

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Annelida												
Capitellidae												
Capitellidae	U	3	0	0	0	0	1	2	1	2	0	9
Chrysopetalidae												
Chrysopetalidae	U	5	0	4	0	1	4	0	0	1	0	15
Paleanotus bellis	N	5	0	3	0	1	4	0	0	1	0	14
Cirratulidae												
Kirkegaardia sp.	U	3	0	0	0	0	0	1	1	0	0	5
Dorvilleidae												
Autolytinae	U	0	0	0	0	0	0	0	0	1	0	1
Dorvilleidae	U	0	0	0	0	0	1	0	0	1	0	2
Hesionidae												
Hesionidae	U	0	0	0	0	1	0	0	0	0	0	1
Lumbrineridae												
Lumbrineridae	U	0	0	0	0	0	1	0	0	0	0	1
Nereididae												
Alitta sp.	U	0	0	0	1	0	0	0	0	0	0	1
Hediste limnicola	N	1	0	0	0	0	0	0	0	0	1	2
Nereididae	U	2	5	1	2	2	3	1	1	3	3	23
Nereis sp.	U	0	1	0	0	0	0	0	0	0	0	1
Platynereis bicanaliculata	N	1	5	1	1	1	2	0	1	2	2	16

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Oligochaeta												
Oligochaeta	U	0	0	0	0	0	0	0	0	1	0	1
Phyllodocidae												
Eulalia quadrioculata	N	0	0	0	0	0	2	0	0	0	1	3
Phyllodocidae	U	0	0	0	0	0	2	0	0	0	1	3
Polynoidae												
Harmothoe imbricata	C	1	0	1	0	2	4	0	1	0	1	10
Polynoidae	U	1	0	2	0	2	3	0	1	0	0	9
Serpulidae												
Pseudochitinopoma sp.	N	0	5	4	0	4	4	0	1	0	1	19
Pseudochitinopoma occidentalis	N	0	5	4	0	4	4	0	1	0	1	19
Serpulidae	U	0	2	3	0	0	3	0	2	1	4	15
Spionidae												
Dipolydora sp.	U	0	0	0	0	0	1	0	0	0	0	1
Marenzelleria arctia	N	0	0	0	0	0	0	0	0	1	0	1
Polydora websteri	C	0	0	0	1	0	1	0	0	5	1	8
Spionidae	U	0	0	0	1	0	2	0	0	5	1	9
Spirorbidae												
Spirorbidae	U	4	0	2	5	4	2	3	4	0	5	29
Syllidae												
Autolytinae	U	0	0	0	0	2	0	0	0	1	0	3
Eusyllinae	U	1	0	0	0	1	0	0	0	0	2	4
Exogone naidina	C	0	0	0	0	0	0	0	1	0	0	1
Exogone sp.	U	0	0	0	0	0	0	0	1	0	0	1
Exogoninae	U	2	0	0	0	0	0	0	1	0	0	3

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Proceraea okadai	I	1	4	4	2	3	3	3	3	4	1	28
Syllidae	U	3	4	4	3	5	4	3	5	4	3	38
Syllinae	U	0	0	1	0	0	2	0	0	0	0	3
Arthropoda												
Amphipoda												
Ampithoe kussakini	N	0	2	0	1	0	0	0	4	1	0	8
Ampithoe sp.	U	0	0	0	0	0	0	1	0	0	0	1
Aoroides columbiae	N	0	0	2	0	2	4	0	0	0	0	8
Aoroides sp.	U	0	0	0	0	2	0	0	0	0	1	3
Calliopiidae	U	0	0	0	0	0	0	0	0	0	1	1
Corophiidae	U	2	2	0	0	0	0	0	0	1	0	5
Crassicorophium sp.	U	0	0	0	0	0	0	0	0	0	1	1
Gnathopleustes pachychaetus	N	0	0	0	0	0	0	0	0	2	0	2
Gnathopleustes pugettensis	N	0	0	0	0	0	0	5	0	3	0	8
Ischyrocerus cf. *anguipes*	C	5	5	0	0	5	5	5	3	3	4	35
Ischyrocerus cf. *minutus*	C	0	1	0	0	0	0	1	0	0	0	2
Ischyrocerus sp.	U	0	0	2	0	0	0	0	0	2	1	5
Jassa staudei	N	0	3	4	0	2	3	2	0	0	0	14
Neopleustes boecki pacifica	C	0	0	0	1	0	0	0	0	0	0	1
Paracalliopiella pratti	N	0	0	0	0	0	0	0	0	0	1	1
Protohyale (Boreohyale) lamberti	N	0	0	0	1	0	0	0	0	0	0	1
Thorlaksonius sp.	U	0	0	0	0	0	0	0	0	0	1	1
Caprellidae												
Caprella drepanochir	N	0	0	2	0	0	0	1	0	0	0	3
Caprella laeviuscula	N	0	2	0	0	2	2	2	0	0	1	9

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Caprella mutica	I	0	0	0	2	0	0	0	1	0	0	3
Caprella sp.	U	0	0	1	1	1	1	2	1	3	2	12
Metacaprella anomala	N	0	1	0	0	3	0	0	0	0	0	4
Metacaprella kennerlyi	N	0	4	1	0	0	3	0	0	0	0	8
Cirripedia												
Balanidae	U	0	2	1	0	0	0	0	1	0	3	7
Balanus crenatus	N	1	2	3	2	5	2	3	1	4	1	24
Balanus glandula	N	4	0	0	3	5	0	5	3	5	1	26
Cirripedia	U	0	0	0	0	0	1	0	0	0	0	1
Decapoda												
Cancridae	U	0	0	1	0	0	0	0	0	0	0	1
Glebocarcinus sp.	U	0	0	3	0	1	1	2	3	0	0	10
Heptacarpus brevirostris	N	0	0	1	0	0	1	0	0	1	0	3
Heptacarpus sp.	U	0	3	0	0	1	0	1	0	0	0	5
Hyas lyratus	N	1	2	2	0	5	0	0	3	1	1	15
Oregonia sp.	U	0	1	1	0	0	0	0	0	0	0	2
Isopoda												
Gnorimosphaeroma oregonense	N	0	0	0	0	0	0	0	1	3	0	4
Gnorimosphaeroma sp.	U	0	0	0	0	0	0	0	0	1	0	1
Munna cf. *halei*	N	1	0	0	0	0	1	0	0	0	0	2
Munna sp.	U	1	0	1	0	1	1	0	0	0	0	4
Munna stephenseni	N	0	0	0	0	0	0	0	0	0	1	1
Pentidotea schmitti	N	0	0	0	0	0	0	1	0	0	0	1
Bryozoa												
Alcyonidium sp.	U	3	4	5	3	2	5	3	0	0	3	28

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Amathia sp. (*Bowerbankia* form)	U	5	0	1	3	0	1	0	1	0	1	12
Callopora craticula	N	0	0	1	0	0	0	0	0	0	0	1
Calloporidae	U	0	0	1	0	0	0	0	0	0	0	1
Celleporella hyalina	C	5	4	3	5	4	5	4	5	5	5	45
Crisularia pacifica	N	5	2	0	4	0	5	0	5	1	1	23
Einhornia crustulenta	C	0	0	0	0	0	0	1	0	0	0	1
Juxtacribrilina sp.	U	2	0	0	3	0	0	0	0	0	4	9
Tegella aquilirostris	N	1	0	0	4	1	4	0	1	0	4	15
Tegella arctica	C	0	0	0	0	0	1	0	0	0	0	1
Chlorophyta												
Algae												
Chlorophyta	U	3	1	1	1	2	3	3	1	3	1	19
Chordata												
Tunicata												
Ascidia callosa	N	3	0	0	0	0	0	0	0	0	0	3
Ascidia cf. *columbiana*	N	0	0	0	0	0	0	0	1	0	0	1
Ascidia sp.	U	1	0	0	2	0	0	0	1	0	0	4
Ascidiidae	U	1	0	0	0	0	0	1	0	0	0	2
Corella inflata	N	0	0	0	0	0	0	0	5	0	0	5
Distaplia alaskensis	N	0	0	4	4	1	0	0	1	0	0	10
Distaplia occidentalis	N	4	0	0	0	0	0	0	1	0	0	5
Distaplia sp.	U	1	0	1	1	2	0	0	1	0	0	6
Molgula citrina	I	4	0	0	0	0	0	0	3	0	0	7
Molgula retortiformis	N	1	0	0	0	0	0	0	3	0	0	4
Molgula sp.	U	1	1	0	0	0	1	0	1	0	0	4

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Stolidobranchia	U	0	0	1	1	1	0	1	0	0	2	6
Styela sp.	U	3	0	0	2	3	0	3	3	0	0	14
Cnidaria												
Anthozoa												
Actiniaria	U	0	2	2	0	1	2	0	0	0	0	7
Anthopleura sp.	U	0	0	0	0	0	1	0	0	0	0	1
Anthozoa	U	0	0	0	0	2	0	0	0	0	0	2
Diadumene sp.	U	0	0	0	0	0	0	0	1	0	0	1
Metridium sp.	U	0	1	0	0	0	0	0	0	0	1	2
Hydrozoa												
Athecata	U	0	1	0	0	0	0	1	1	0	0	3
Campanulariidae	U	2	5	5	5	5	5	5	4	4	4	44
Campanulinidae	U	0	0	0	0	0	0	0	0	3	0	3
Corynidae	U	0	0	1	1	5	1	2	0	2	0	12
Hydrozoa sp. C	U	0	0	0	3	1	0	0	2	0	0	6
Hydrozoa sp. D	U	0	0	1	0	0	2	0	0	1	0	4
Thecata	U	0	0	0	0	0	0	0	0	0	1	1
Scyphozoa												
Scyphozoa	U	0	0	0	0	0	0	1	4	2	0	7
Echinodermata												
Asteroidea												
Asteroidea	U	0	4	1	0	0	4	0	0	0	0	9
Echinodermata												
Echinoidea												
Echinoidea	U	0	1	0	1	0	2	0	0	0	0	4

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Entoprocta												
Kamptozoa												
Kamptozoa	U	0	0	0	0	0	0	0	1	0	0	1
Loxosomatidae	U	0	0	0	0	0	1	0	0	0	0	1
Mollusca												
Bivalvia												
Clam	U	0	0	0	0	0	0	1	0	0	0	1
Hiatella arctica	N	5	4	5	2	0	5	1	0	4	1	27
Modiolus modiolus	N	3	4	2	4	1	3	3	2	0	1	23
Mytilidae	U	2	0	2	1	2	0	0	0	0	3	10
Mytilus galloprovincialis/trossulus complex	U	1	4	1	1	0	3	3	0	5	0	18
Pododesmus macrochisma	N	0	1	0	0	0	1	0	0	0	0	2
Turtonia minuta	N	0	0	0	0	0	0	3	1	0	0	4
Veneridae	U	0	0	0	0	0	0	0	0	1	0	1
Gastropoda												
Columbellidae	U	0	1	0	0	0	1	0	0	0	0	2
Gastropoda	U	0	0	0	0	1	0	0	0	0	0	1
Lacuna porrecta	N	0	1	0	0	0	0	1	0	0	2	4
Lacuna vincta	U	1	5	0	0	3	3	4	1	5	2	24
Limpet	U	0	0	0	0	0	0	1	0	0	0	1
Littorinidae	U	0	0	0	0	0	0	0	1	0	0	1
Margarites pupillus	N	0	0	0	0	1	2	0	0	0	1	4
Odostomia sp.	U	0	0	0	0	0	0	0	0	1	0	1
Rissoidae	U	0	0	0	0	0	0	0	0	2	0	2
Velutina velutina	C	0	0	2	0	0	0	0	0	0	0	2

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Nudibranchia												
Acanthodoris atrogriseata	N	0	0	2	0	0	3	0	0	0	0	5
Aeolidia papillosa	C	0	0	1	0	0	0	0	0	0	0	1
Aeolidioidea	U	1	0	1	0	0	0	0	0	2	0	4
Coryphella verrucosa	N	1	1	1	0	0	0	0	0	3	0	6
Dendronotus venustus	N	0	2	0	0	1	1	4	1	0	1	10
Eubranchulus rupium	C	0	0	0	2	3	1	3	0	4	2	15
Eubranchus sp.	U	0	0	0	0	1	0	1	0	1	0	3
Fiocuthona concinna	C	0	0	0	0	0	0	0	0	2	0	2
Hermissenda crassicornis	N	0	0	0	0	0	0	0	0	0	1	1
Onchidoris bilamellata	N	0	1	2	2	0	1	0	0	0	0	6
Onchidoris muricata	N	0	0	0	0	0	1	0	0	0	0	1
Palio zosterae	N	0	0	0	0	0	1	0	0	0	0	1
Tenellia albocrusta	N	0	1	3	0	0	0	0	0	1	1	6
Polyplacophora												
Chitonida	U	0	0	0	0	1	1	0	0	0	1	3
Nemertea												
Nemertea												
Nemertea	U	0	0	2	1	0	0	1	0	0	0	4
Phaeophyceae												
Algae												
Phaeophyceae	U	1	2	0	0	1	1	1	0	0	0	6
Platyhelminthes												
Platyhelminthes												
Acerotisa	U	0	0	0	0	1	0	0	0	0	1	2

Taxon	Invasion Status	Bootlegger Cove	Halibut Cove - Brenda D	Homer Spit Deep Water Dock	Homer Spit Marina	Kasitsna Bay Lab Dock	Peterson Bay Aquaculture Farm	Port Graham	Seldovia Harbor	Tutka Bay Hatchery	Tutka Bay Wilderness Lodge	NumPanels
Leptoplanidae	U	0	0	1	2	3	2	0	0	1	0	9
Platyhelminthes	U	2	2	5	5	5	4	0	2	2	4	31
Porifera												
Porifera												
Porifera sp. B	U	0	0	0	0	0	1	0	0	0	0	1
Porifera sp. C	U	3	0	0	2	0	0	0	1	0	0	6
Protozoa												
Protista												
Protista sp. B	U	0	0	0	0	0	0	0	2	0	0	2
Protista sp. D	U	4	0	0	2	3	3	4	5	1	3	25
Protista sp. E	U	0	0	0	0	0	0	0	1	0	0	1
Protista sp. F	U	0	0	0	0	2	0	0	0	0	0	2
Rhodophyta												
Algae												
Rhodophyta	U	2	2	1	0	1	4	4	4	2	0	20

Appendix 2: Relative Abundance of Sessile NIS per Plate within Bays

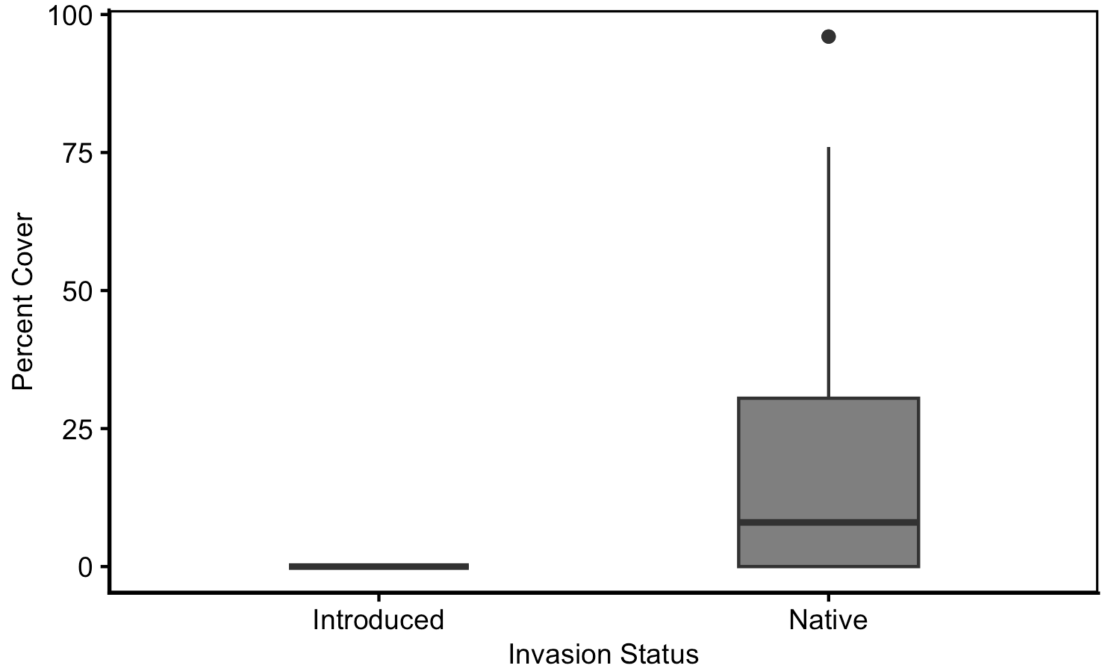

Figure A2.1: Measures of percent cover of NIS (upper) and native species (lower) on plates for sessile taxa only. Percent cover was calculated using point count measurements (50 points/plate and 50 plates total), identifying primary (base) space occupation by sessile invertebrate species. Status as native or NIS is designated based on literature and the NEMESIS database (Fofonoff et al. 2018). The lower and upper hinges of the box plots correspond to the first and third quartiles (the 25th and 75th percentiles); center line with boxes indicates medians, lines indicate 95% confidence limits, and points indicate samples that extended beyond these limits.