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# A database of paleoceanographic sediment cores from the North Pacific, 1951-2016

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## Abstract

We assessed sediment coring, data acquisition, and publications from the North Pacific (north of 30˚N) from 1951-2016. There are 2134 sediment cores collected by American, French, Japanese, Russian, and international research vessels across the North Pacific (including the Pacific Subarctic Gyre, Alaskan Gyre, Japan Margin, and California Margin, 1391 cores), Sea of Okhotsk (271 cores), Bering Sea (123 cores), and Sea of Japan (349 cores) reported here. All existing metadata associated with these sediment cores are documented, including coring date, location, core number, cruise number, water depth, vessel metadata, and coring technology. North Pacific age models are based on isotope stratigraphy, radiocarbon dating, magnetostratigraphy, biostratigraphy, tephrochronology, % opal, color, and lithophysical proxies. Here, we evaluate the iterative generation of each published age model and provide documentation of each dating technique used, as well as sedimentation rates and age ranges. We categorized cores according to availability of a variety of proxy evidence, including biological (e.g. benthic and planktonic foraminifera assemblages), geochemical (e.g. heavy metal concentrations), isotopic (e.g. bulk sediment nitrogen and carbon isotopes), and stratigraphic (e.g. preserved laminations) proxies. This database is a unique resource to the paleoceanographic and paleoclimate communities, and provides cohesive accessibility to sedimentary sequences, age model development, and proxies. The data set is publicly available through PANGAEA at doi:https://doi.pangaea.de/10.1594/PANGAEA.875998.

## 1 Introduction

Paleoceanographic sediments provide the sedimentary, geochemical, and biological evidence of past earth system changes, and are one of the primary ways to investigate past changes in global and regional climate, ocean circulation, volcanism, and biogeochemical cycles, among many other ocean-related inquiries. Sediment cores are collected from the seafloor during oceanographic research cruises. After collection, sediment cores are processed, archived, analyzed, and the results are published in a scientific journal. Mechanistic hypotheses investigated by sediment core research include ocean-basin scale changes in deep ocean circulation (e.g. Rae et al., 2014; De Pol-Holz et al., 2006), deep-water and intermediate water formation and ventilation (e.g. Knudson and Ravelo, 2015a; Zheng et al., 2000; Cook et al., 2016), and changes in the oceanic preformed nutrient inventories (e.g. Jaccard and Galbraith, 2013; Knudson and Ravelo, 2015b), as well as more regional mechanisms such as sea ice extent (e.g. Max et al., 2012), upwelling intensity (e.g. Di Lorenzo et al., 2008; Hendy et al., 2004), local surface ocean productivity (e.g. Serno et al., 2014; Venti et al., 2017), and terrigenous and marine fluxes of iron (e.g. Davies et al., 2011; Praetorius et al., 2015).

When taken together, suites of cores can create robust reconstructions of large oceanographic provinces, and provide insight into earth system mechanistic hypotheses. However, there is not a common repository for paleoceanographic data and publications, and this lack of centralization limits the efficacy of the earth science community to direct research efforts. Paleoceanographers have benefited from the use of large databases of climate data in the past, such as CLIMAP (Climate: Long Range Investigation, Mapping, Prediction), which produced globally resolved temperature records for the Last Glacial Maximum (LGM) and aimed to determine climate system sensitivity from paleoclimate reconstructions (Hoffert & Covey 1992). The PaleoDeepDive project employed a similar approach to the systematic extraction of archival data and constructed a new way to assess and engage with paleobiological data (Zhang, 2015). These projects are examples of international research teams approaching the same limit—extraction and organization of dark data—that arises when creating comprehensive paleo-reconstructions.

### 1.1 Assembling a paleoceanographic database

There is a clear need to generate high quality paleo-environmental reconstructions and fit the North Pacific into the global paleoceanographic framework, because the role this enormous ocean basin plays in earth system changes remains unclear relative to its Southern Ocean and North Atlantic counterparts. We present here a comprehensive database of 2134 sediment cores which may be utilized to generate a broader context for the history of large oceanographic provinces as well as contained regional processes. Here we describe this new database and the broad-scale findings of our census of coring metadata, age model development, and proxy publications. We address the following questions in this manuscript to supplement and provide context for our database:

1. Where have sediment cores been extracted from the North Pacific (North of 30˚N, including the Pacific Subarctic Gyre, Alaskan Gyre, Japan Margin, and California Margin), the Bering Sea, the Sea of Okhotsk, and the Sea of Japan? What metadata is available—regarding core name, recovery date, recovery vessel and scientific agency, latitude and longitude, water depth, core length, and coring technology in published cruise reports or peer-reviewed investigations?
2. For sediment cores with published age models—what lines of evidence were used to develop the chronological age of the sediment, what is the age range from core top to core bottom, and what are the sedimentation rates?
3. What lines of sedimentary, geochemical, isotopic, and biological proxy evidence are available for each sediment core?
4. What is the state of sediment core research effort and metadata reporting since the beginning of paleoceanographic core research?

### 1.2 Age model development, paleoceanographic proxies, and cruise-core nomenclature,

Marine sedimentary age models tie the sedimentary depth (in meters below sediment surface) to calendar age (ka, thousands of years), and the dating techniques used to complete these chronologies depend on the quality, preservation, and age of the sediments, as well as the investigative priorities of research teams and the proximity of other well-developed sedimentary chronologies. Not all sedimentary chronologies are of the same quality. Building a database with all dating techniques parsed and age models iterations captured, along with reported sedimentation rates and the sedimentary age ranges, will provide investigators with the capacity to quickly evaluate the specific cores that meet the investigative priorities. In turn, paleoceanographic proxies are a diverse suite of biological, isotopic, geochemical, and sedimentary observations and measurements taken from sediments. A catalogue of paleoceanographic proxies, and associated publications, provides an efficient resource for assessing the availability and quality of many different lines of evidence.

Sediment cores are often represented by their cruise-core unique identifier, which has the general format "cruise name-core number". The cruise number is generally indicative of the research vessel employed and the year of the expedition, for example, YK07-12 is the 12th cruise of R/V Yokosuka in 2007. Cruise L13-81 is the 13th cruise of S.P. Lee in 1981, and MR06-04 is the 4th cruise of R/V Mirai in 2006. Often the core number will be preceded by a PC (piston core), MC (multicore), TC (trigger core), or GC (gravity core) to signify the coring technology. The sediment core B37-04G is the 4th gravity core from the 37th cruise of R/V Professor Bogorov, and EW9504-11PC is the 11th piston core from the fourth cruise of R/V Maurice Ewing in 1995. However, this nomenclature is not comprehensive, and for example cores affiliated with iterations of the International Ocean Discovery Program are represented by the program abbreviation and their hole number (i.e. ODP Hole 1209A). The cruise name or number is unknown for many cores, and in these cases, the core is referred to by its number.

## 2 Methods

Here we assemble a database from peer-reviewed publications, publicly available online cruise reports, and print-only cruise reports available through the University of Washington library network. Detailed metadata is reported for cores where it is available, commonly from cruise reports, including water depth (in meters), recovery year, latitude and longitude, coring technology, and core length (in meters). Summary details regarding affiliated research vessels and institutions were gathered from publications or cruise reports. Here we catalog the methodological approaches taken to develop age models in the North Pacific by tracking the sequential publications to capture each iteration and line of evidence used in the most up-to-date published version. We reported core top and bottom ages, along with sedimentation rates. For each core, we documented published proxy evidence, including isotopes stratigraphy, geochemistry, micropaleontology, and sediment analyses.

## 3.0 Results

### 3.1 Sediment coring and metadata

We documented 2134 sediment cores and 283 marine geology research cruises above 30°N, from 1951 to 2016, in the North Pacific, the Bering Sea, the Sea of Japan, and the Sea of Okhotsk (Figure 1, Table 1). The majority of sediment cores were extracted from the Northern Subarctic Pacific (1391 cores), followed by the Sea of Japan (349 cores), the Sea of Okhotsk (271 cores), and the Bering Sea (123 cores). Many of the oldest cores in this oceanographic province come from the central abyssal Pacific and are associated with cruises of the Deep Sea Drilling Project. The recovery ages of cores range from 1951- 2010 (Figure 1, Table 1). Frequently, metadata associated with sediment cores or marine research cruises are unavailable to the public or omitted from publications affiliated with sediment cores. For example, 495 cores are in the literature without recovery year, 354 sediment cores were published without latitude and longitude, and 642 cores were reported without specifying the coring technology used (Table 1, 2). Even more, 1210 ancillary sediment cores reported in our database were identified in supplemental tables within publications, however no original cruise reports or peer-reviewed publications otherwise report on these cores.

## 3.2 Sediment chronologies

In the North Pacific, 519 marine sediment cores have published age models, and 266 of these chronologies are generated with radiocarbon dating ($^{14}C$) of materials such as planktonic foraminifera, molluscs, and terrigenous material like bark or wood fragments (Figure 2). Radiocarbon dating is the most common chronological technique region-wide (51% of age models incorporate this method). Lead dating ($^{210}Pb$) is used for 12 sediment chronologies. Many other lines of evidence are used in the North Pacific and marginal seas to develop paleoceanographic age models. These approaches vary regionally and include planktonic foraminifera oxygen isotope stratigraphy, diatom silica oxygen isotope stratigraphy, biostratigraphy, magnetostratigraphy, tephrochronology, chronostratigraphy, carbonate stratigraphy, opal stratigraphy, composition, lithophysical proxies, the presence of lamination, chlorin content, and color (a*, b*, and L* values) (Figure 2, Table 3). For example, in the Sea of Japan, lithophysical proxies such as core laminations are often utilized as chronological proxy evidence, and 12% of local core age models incorporate this technique. Tephrochronology is also applied in 51% of Sea of Japan age models due to regional volcanism. In the Bering Sea, peaks in silica are often used, and 13% of the regional age models incorporated this technique. Published sedimentation rates ranged across the North Pacific (0.1-2000 cm/ka), Bering Sea (3-250 cm/ka), Sea of Okhotsk (0.7-250 cm/ka), and the Sea of Japan (0.2-74 cm/ka), with the highest rates within the Alaska Current in the North Pacific (up to 2000 cm/ka).

## 3.3 Paleoceanographic proxies from marine sediment cores

From all reported sediment cores in the North Pacific and marginal seas, 40% of cores have published proxy data (Figure 3, 4). Stable isotope stratigraphy is available for 293 cores, including oxygen, carbon, and nitrogen isotopes ($\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$) from planktonic and benthic foraminifera. We documented 236 cores with planktonic foraminifera oxygen isotopes, 178 cores with benthic foraminifera oxygen isotopes, 67 cores with planktonic foraminifera carbon isotopes, 77 cores with benthic foraminifera carbon isotopes, and 34 cores with bulk sediment nitrogen isotopes (Table 4). The lines of proxy evidence documented in the database address large thematic questions in paleoceanography, including ocean temperature, paleo-biology, seafloor geochemistry, sea ice distribution, and additional sedimentary analyses (Figure 3, Table 4).

We recorded paleothermometry data for 234 cores. Sea surface temperature is reconstructed using planktonic foraminifera oxygen isotopes ($\delta^{18}O_p$), magnesium/calcium ratios from planktonic foraminifera, and alkenones, including $TEX_{86}$, and $U^k_{37}$ (Figure 3). We recorded 425 cores with biostratigraphy and assemblage abundance data for foraminifera, diatom, radiolarian, ostracod, silicoflagellate, ebridian, acritarch, coccolithophore, and dinoflagellate assemblages (Figure 3, Table 4). Biostratigraphy utilizes known microfossil assemblages and their corresponding ages to assign a geologic date to core strata containing assemblages.  Geochemical analysis is reported for 151 cores (Figure 3, Table 3). Geochemical data comes from measurements of, for example, brassicasterol, magnesium, calcium, molybdenum, cadmium, manganese, uranium, chromium, rhenium, chlorin, titanium, iron, zinc, and beryllium. We documented 234 cores with sea ice proxy data (Figure 3). Sea ice proxies include geochemical biomarker IP25, ice-rafted debris (IRD), and diatom communities exclusive to sea ice environments. The presence and concentration of these proxies are indicative of contemporary sea ice extent and volume. We recorded 521 sediment cores with lithophysical analyses, including the documentation of core lamina, sediment density, mass accumulation rates, biogenic opal and barium, silicon/aluminum weight ratios, carbon/nitrogen ratios, inorganic and organic calcium carbonate and carbon, inorganic nitrogen, sulfur, and clay mineral composition (Figure 3).

### 3.4 Research cruise and publication rate

We cataloged 565 peer-reviewed publications and cruise reports and evaluated the progress of paleoceanographic research using a suite of annual assessments of cruise and core metadata and publications. We evaluated the annual number of age models published (using any dating technique), age models published specifically with radiocarbon dating, publications generated, sediment cores collected, research cruises completed, and the mean number of proxies generated per core (Figure 4). Cruise reports were not publicly available for every cruise or core, and many cores cited in cruise reports were never published upon in peer-reviewed literature. The number of affiliated publications and cruise reports per core ranged from 0 to 23 publications (Figure 5). Only 41 cores have more than 6 publications, while the majority of cores (1210 cores, or 57% of all cores extracted from the North Pacific) lack any publication.

The state of North Pacific paleoceanographic investigations has evolved incrementally in the 65-year history of research in the region, and we characterize the history into two distinct phases (before and after the early 1990s). Core recovery rates were high from 1951-1988, a period when expeditions were driven by individual institutions, wherein peer-reviewed publication was not the primary research outcome and therefore publication rates were low (Figure 4). Annual rates of cruise completion and sediment core extraction peaked in 1965-1968, and this is a consequence of the temporal overlap in peak research efforts by Scripps Institute of Oceanography (1951-1988), Lamont-Doherty Earth Observatory (1964-1975), Oregon State University (1962-1972), and the Deep Sea Drilling Project (1971-1982).

Annual rates of publication (peer-reviewed and cruise reports), including those publications with age models, increased around 1995 (Figure 4). In this later period, research cruise efforts were dominated by international research team efforts and resulted in increased peer-reviewed publications, sediment core chronology constructions, and proliferation of radiocarbon dating. There are 41 cores with the highest level of documentation (>6 publications), and these archives are primarily located within the California Current (Figure 5). Major peaks in cruising and coring efforts coincided with research cruises by the International Ocean Discovery Program, such as ODP Legs 145 and 146 in 1992 (North Pacific Transect, Cascadia Margin), ODP Leg 167 in 1996 (California Margin), and IODP Expedition 323 in 2009 (Bering Sea). Despite the increase in publications around 1995, we observe no distinct temporal trend in the rate of cruise completion and coring effort (Figure 4).

## 4 Discussion

### 4.1 Evolving state of North Pacific coring and paleoceanographic approaches

Extensive cruise and research efforts have focused on the marine geology of the North Pacific. Often, the cruise and core metadata from these efforts is unpublished, though they are integral to collaboration, continued research, and publication. Here, we present a database with 2134 sediment cores, 283 research cruises, and 565 peer-reviewed publications related to paleoceanographic research (Table 1). We cataloged 519 publications with sedimentary age models, and of those age models 266 utilize radiocarbon dating. Throughout the North Pacific, Bering Sea, Sea of Okhotsk, and Sea of Japan, the techniques for reconstructing sedimentary age models regionally varied. Our database encompasses all available lines of proxy evidence for sea surface temperature reconstructions, paleobiological assemblages, seafloor geochemistry, sea ice reconstruction, and other sedimentary analyses. We observe and discuss two distinct periods of research and publication effort (before and after the early 90s) (Figure 4).

We documented a community-wide shift away from singular dating techniques toward age models which incorporate several techniques. Multiproxy approaches hold merit through verifying or constraining the results of a singular proxy, and thereby disentangling multiple environmental drivers and providing redundancy in order to create records of climate and ocean conditions from sediment cores (Mix et al., 2000; Mann, 2002). Publication count and age model development has increased through the last 60 years and evolved from singular dating techniques to more detailed high-resolution age models constructed to investigate millennial and submillennial paleoceanographic variability (Figure 4, 5).

### 4.2 The merit of database management and open-access science

Databases are integral to facilitate efficient, hypothesis-based investigations into earth system mechanisms. Public access to databases facilitate a higher volume of research by a diverse range of scientists (Harnad and Brody 2004). The necessity for databases to encompass a wide array of data over large oceanographic provinces is also largely recognized. Open access tools from PANGAEA support database-dependent research, because hypothesis-based investigations can be make more efficient through public access. For example, content from online databases has contributed to research in atmospheric forcing (e.g. Shaffer et al., 2009), Atlantic Meridional Overturning Circulation (AMOC, e.g. Schmittner and Galbraith, 2008), and Southern Ocean ventilation (e.g. Yamamoto et al., 2015). The metadata in these databases must be thorough, as data is impractical without the affiliated identifier, location, and methods (Lehnert et al., 2000). Database management should be a priority in any field that incorporates the contents of online repositories of knowledge and research. The disconnect between the research goals of the paleoceanographic community and the metadata produced here can be described as a "breakdown", a limit on the progress of paleoceanographic research (Tanweer et al., 2016). These breakdowns allow us to self-assess and move forward with insight into best practices. Metadata is produced from datasets that are inherently human in design, and therefore are not inerrant. Assessment of the errors in metadata reporting can directly reveal the need for community-wide improvements. As an example, all cores should be reported with latitude and longitude; the absence of this specific metadata significantly impairs further work. The database presented here, as well as others like it, consolidates the research effort of an entire community into an efficient tool for future investigative purposes.

### 4.3 Recommendations for the marine geology community

Ocean sediment records are one of the primary tools for understanding earth's history, and the documentation of these records benefits the entire community of earth scientists. The publications and cruise reports here represent a large body of research completed on North Pacific sediment records, however this may not constitute the entire body of work. We demonstrate here a need for more thorough, accessible documentation of marine geology and paleoceanographic research. In our examination of publications, cruise reports, and notes from research cruises, we gained insights into past inconsistencies in marine sediment record reporting. We recommend a suite actions to ensure efficient, comprehensive sediment core collection, metadata documentation, and the publication of chronologies and proxies. We propose that each publication thoroughly reports metadata on all cores discussed, and their associated cruises, including core unique identifier numbers, cruise name and number, vessel name, geographic coordinates, core recovery date, core length, core recovery water depth (meters below sea level), sampling resolution, sampling volume, core archival repository, and the link (if existing) to public cruise reports. We also suggest summarizing each core's metadata, age model, and publication history of previous publications in the methods section in order to provide a frame of reference for new findings, especially in the context of iterative age model revisions.

## 5 Author Contribution

S. E. Myhre and C. V. Davis initiated the building of this database. M. Borreggine and S. E. Myhre built the database and were joined by K. A. S. Mislan in producing figures and analysis for this manuscript. All authors wrote the manuscript.

## 6 Acknowledgements

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## Figure and Tables

**Table 1**. Regional summary of sediment core database for the Bering Sea, North Pacific, Sea of Japan, and Sea of Okhotsk, including number of cores recovered, the regional percent (%) of cores reported with latitude and longitude, number of research cruises, total regional publication count, count of cores with no peer-reviewed publications or cruise report, the range of core recovery years, the regional percent (%) of cores reported with recovery years, and the range of recovered core water depths (meters below sea level).

| Region | Bering Sea | North Pacific | Sea of Japan | Sea of Okhotsk | Total |
|---|---|---|---|---|---|
| Count of cruises | 24 | 179 | 78 | 31 | 283 |
| Count of publications | 70 | 306 | 114 | 90 | 565 |
| Count of cores with no publications* or cruise report | 61 | 849 | 172 | 128 | 1210 |
| Number of cores recovered | 123 | 1391 | 349 | 271 | 2134 |
| Percent of regional cores (%) reported with latitude and longitude | 91.9 | 81.9 | 77.7 | 91.9 | 83.4 |
| Range of core recovery years | 1957-2009 | 1951-2009 | 1957-2010 | 1972-2009 | 1951-2010 |
| Percent of regional cores (%) reported with recovery year | 87 | 68.9 | 96.9 | 98.5 | 76.8 |
| Range of recovered core water depths (meters below sea level) | 33-3930 | 21-9585 | 129-5986 | 105-8180 | 21-9585 |

[*] These cores are listed in large data tables in auxiliary publications, but the original reporting is not publicly available.

**Table 2.** Percent of regional cores reported with coring technology, and the number of cores recovered in the North Pacific and marginal seas by coring technology. Additional reported coring technologies include the less often utilized Hydrostatic cores, Kasten cores, Asura cores, Pressure cores, and Trigger cores.

| **Region** | **Bering Sea** | **North Pacific** | **Sea of Japan** | **Sea of Okhotsk** |
|---|---|---|---|---|
| **% of regional cores reported with drilling technology** | 75.6 | 72.1 | 60.2 | 68.6 |
| **# of Piston cores** | 33 | 476 | 177 | 67 |
| **# of Gravity cores** | 11 | 250 | 15 | 73 |
| **# of Box cores** | 2 | 78 | 1 | 1 |
| **# of Riserless Drilling cores** | 7 | 52 | 0 | 0 |
| **# of Multicores** | 33 | 39 | 1 | 39 |
| **# of Phleger cores** | 0 | 15 | 0 | 0 |
| **# of Jumbo Piston cores** | 4 | 10 | 0 | 0 |

**Table 3.** Summary statistics on core chronology, including the number of cores with radiocarbon dating ($^{14}$C) and oxygen isotope stratigraphy of planktonic foraminifera ($\delta^{18}$O), as well as the regional mean core top and bottom ages, and the number of cores with published sedimentation rate ranges and means.

| **Region** | **Bering Sea** | **North Pacific** | **Sea of Japan** | **Sea of Okhotsk** |
|---|---|---|---|---|
| **$^{14}$C Dating** | 28 | 158 | 38 | 42 |
| **$\delta^{18}$O Stratigraphy, Planktonic foraminifera** | 20 | 122 | 29 | 32 |
| **Mean core top age (Calendar age, ka)** | 6.0 ± 9.6 | 9.5 ± 61.6 | 5.9 ± 28.4 | 1.1 ± 2.3 |
| **Mean core bottom age (Calendar age, ka)** | 523.7 ± 1146.2 | 6210.8 ± 20250.7 | 996.1 ± 2602.2 | 153.1 ± 279.2 |
| **Cores with sedimentation rate range** | 28 | 97 | 20 | 18 |
| **Cores with sedimentation rate mean** | 7 | 68 | 9 | 16 |

**Table 4.** Regional summary of isotopic, geochemical, biological, and sedimentary proxies. Benthic and planktonic isotopic analysis is for all cores, including, but not limited to, isotope analysis used in core chronology development.

| **Region** | **Bering Sea** | **North Pacific** | **Sea of Japan** | **Sea of Okhotsk** |
|---|---|---|---|---|
| **$\delta^{18}O_b$** | 19 | 118 | 15 | 25 |
| **$\delta^{18}O_p$** | 20 | 139 | 45 | 32 |
| **$\delta^{13}C_b$** | 7 | 57 | 7 | 6 |
| **$\delta^{13}C_p$** | 6 | 50 | 10 | 1 |
| **$\delta^{15}N$** | 5 | 16 | 12 | 1 |
| **Alkenone $U^{K'}_{37}$** | 7 | 64 | 15 | 12 |
| **$TEX_{86}$** | 0 | 1 | 0 | 0 |
| **Foraminiferal Biostratigraphy** | 12 | 82 | 22 | 8 |
| **Foraminiferal Abundance** | 8 | 53 | 41 | 18 |
| **Diatom Biostratigraphy** | 35 | 87 | 49 | 25 |
| **Geochemical Proxies (Mg, Mo, Cd, Mn, U, Cr, Re, Ca, T, Fe, Mg, Zn, Be, Chlorin)** | 1 | 189 | 46 | 27 |
| **% Opal** | 21 | 38 | 20 | 20 |
| **Total Inorganic Carbon (%)** | 16 | 204 | 49 | 26 |
| **Total Organic Carbon (%)** | 16 | 142 | 62 | 26 |

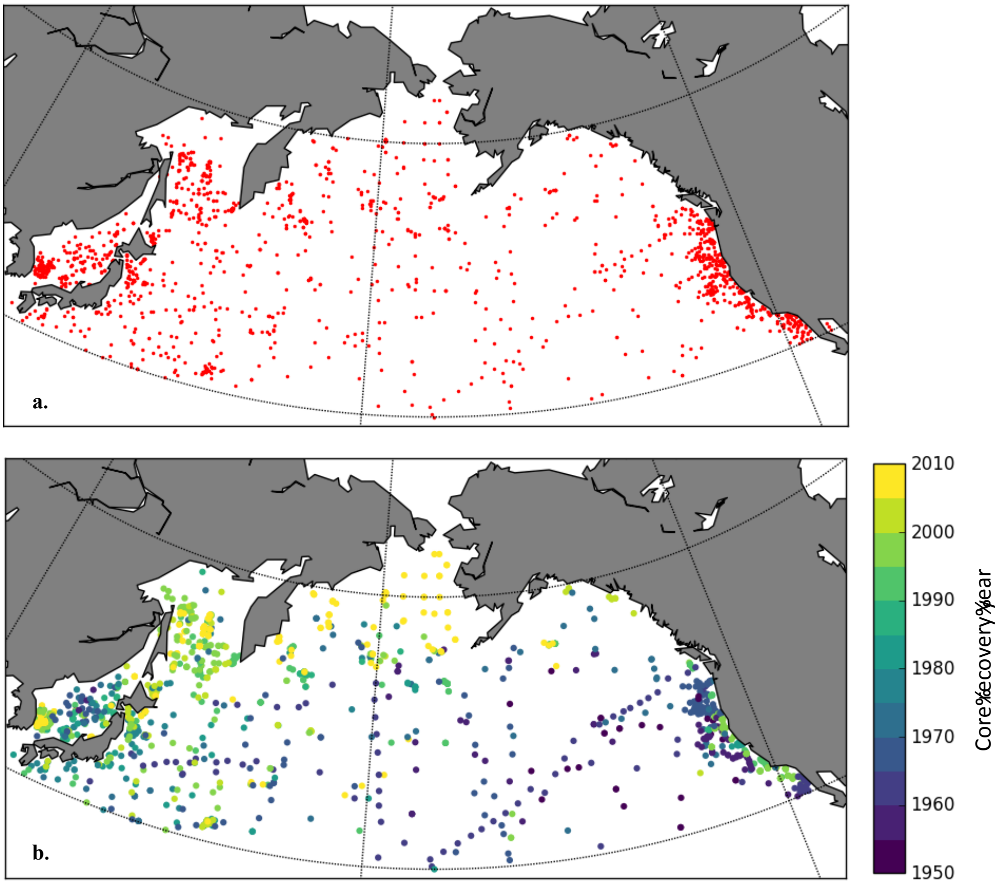

**Figure 1.** Location and recovery year of marine sediment cores from the North Pacific and marginal seas. **a.** Sediment cores in the North Pacific (above 30°N) published latitudes and longitudes (354 additional cores were documented in either cruise reports or peer-reviewed publications without latitude and longitude). **b.** Sediment cores published with an associated core recovery year, ranging from 1951-2010, and this age range corresponds with the color bar (495 cores have been published in either cruise reports or peer-reviewed publications without recovery year).

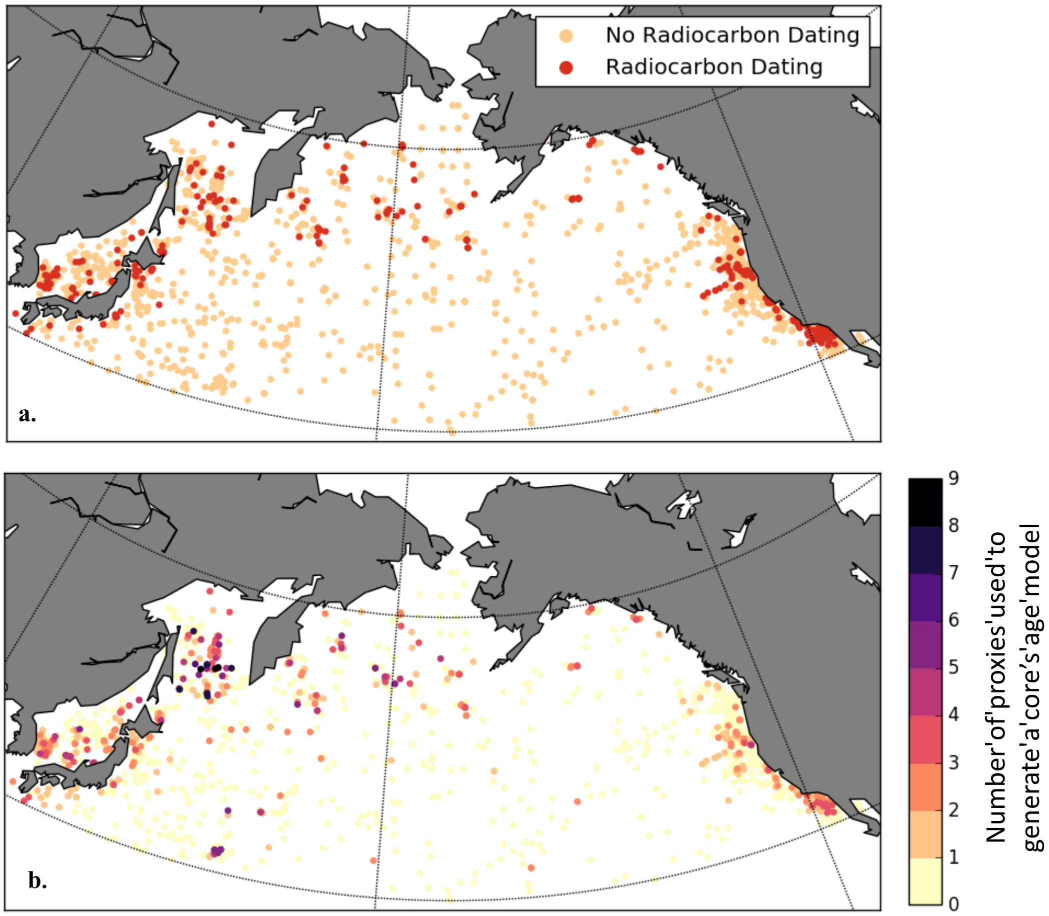

**Figure 2.** Age model development for sediment cores in the North Pacific and marginal seas. **a.** Cores with age models that have been constructed with radiocarbon dating ($^{14}C$). **b.** Number of paleoceanographic proxies used to generate each core's age model.

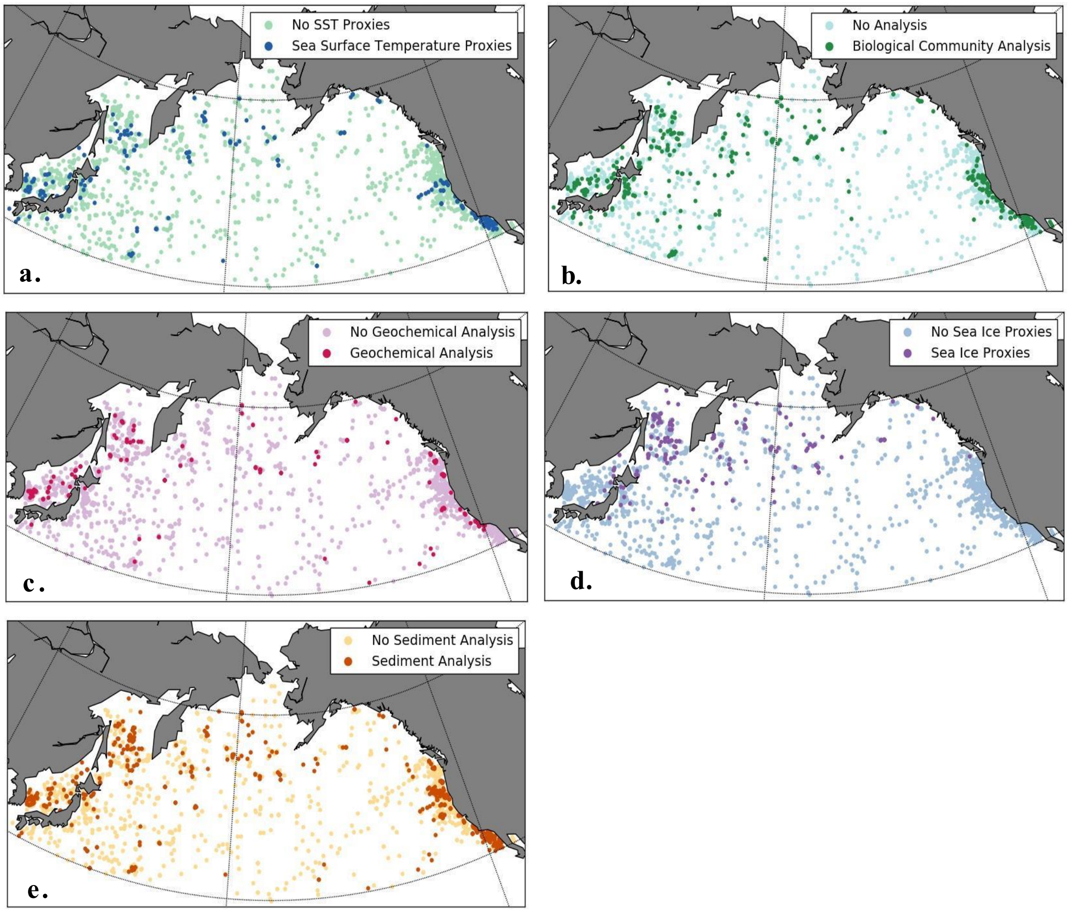

**Figure 3.** Published paleoceanographic proxies in the North Pacific. a. sea surface temperature reconstructions including planktonic foraminifera oxygen isotopes ($\delta^{18}O_p$), magnesium/calcium measurements, $TEX_{86}$, and $U^{k}_{37}$ alkenones b. biostratigraphy of microfossils, including foraminifera, diatoms, radiolarians, ostracods, silicoflagellates, ebridians, acritarchs, coccolithophores, and dinoflagellates **c.** geochemical proxy analysis, including trace metals such as brassicasterol, magnesium, calcium, molybdenum, cadmium, manganese, uranium, chromium, rhenium, chlorin, titanium, iron, zinc, and beryllium **d.** presence of sea ice proxies including geochemical biomarker IP25, ice-rafted debris (IRD), and sea ice related diatom communities **e.** analysis of lithophysical core proxies, including measurements of core lamina, biogenic opal and barium, silicon/aluminum weight ratio, sulfur, inorganic

and organic carbon weight and mass accumulation rates, mass accumulation rates of various elements, inorganic nitrogen, carbon to nitrogen ratios, sediment density, and clay mineral composition.

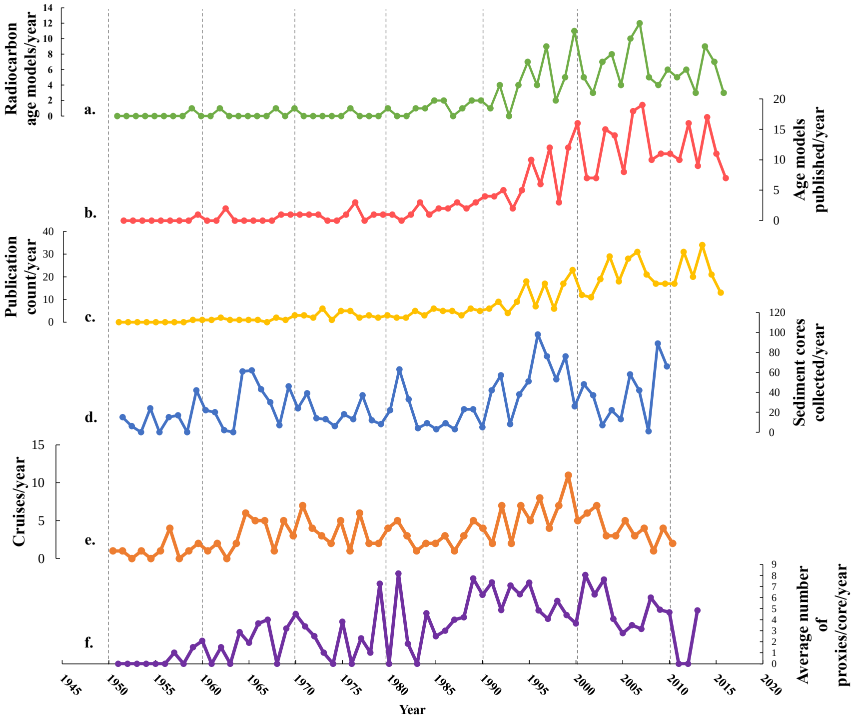

**Figure 4.** North Pacific and marginal seas marine geology cruise and paleoceanographic research progress through time, wherein the lead-lag timing of cruise reporting and core publication is assumed for the most recent years. We utilize peer-reviewed publications to locate cores, and there is a lag between publication and core extraction. **a.** Annual number of age models published using radiocarbon dating. **b.** Annual number of all age models published. **c.** Total annual number of publications and cruise reports. **d.** Annual number of cores collected. **e.** Marine research expedition count per year. **f.** Annual mean number of proxy analyses published per core.

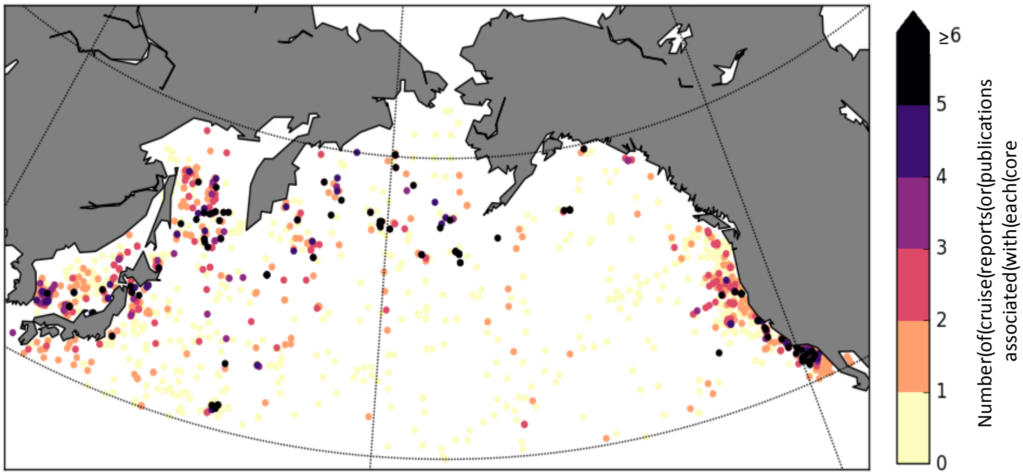

**Figure 5.** Number of affiliated publications and cruise reports for each core. Maximum publication count for an individual core is 23.

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