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Key Points:
- At present, 24% of all benthic marine calcifiers experience Mg-calcite undersaturation
- A 50% reduction in [CO_3^{2-}] owing to future OA will cause 57% of all marine benthic calcifiers to experience undersaturation
- To predict responses of calcifying organisms to OA, species-specific mineral compositions must be considered

Supporting Information:
- Supporting Information S1

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Benthic marine calcifiers coexist with $CaCO_3$-undersaturated seawater worldwide

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Abstract Ocean acidification and decreasing seawater saturation state with respect to calcium carbonate ($CaCO_3$) minerals have raised concerns about the consequences to marine organisms that build $CaCO_3$ structures. A large proportion of benthic marine calcifiers incorporate Mg^{2+} into their skeletons (Mg-calcite), which, in general, reduces mineral stability. The relative vulnerability of some marine calcifiers to ocean acidification appears linked to the relative solubility of their shell or skeletal mineralogy, although some organisms have sophisticated mechanisms for constructing and maintaining their $CaCO_3$ structures causing deviation from this dependence. Nevertheless, few studies consider seawater saturation state with respect to the actual Mg-calcite mineralogy ($\Omega_{Mg\text{-}x}$) of a species when evaluating the effect of ocean acidification on that species. Here, a global dataset of skeletal mole % $MgCO_3$ of benthic calcifiers and in situ environmental conditions spanning a depth range of 0 m (subtidal/neritic) to 5600 m (abyssal) was assembled to calculate in situ $\Omega_{Mg\text{-}x}$. This analysis shows that 24% of the studied benthic calcifiers currently experience seawater mineral undersaturation ($\Omega_{Mg\text{-}x} < 1$). As a result of ongoing anthropogenic ocean acidification over the next 200 to 3000 years, the predicted decrease in seawater mineral saturation will expose approximately 57% of all studied benthic calcifying species to seawater undersaturation. These observations reveal a surprisingly high proportion of benthic marine calcifiers exposed to seawater that is undersaturated with respect to their skeletal mineralogy, underscoring the importance of using species-specific seawater mineral saturation states when investigating the impact of CO_2-induced ocean acidification on benthic marine calcification.

1. Introduction

Rising atmospheric pCO_2 and subsequent ocean acidification are expected to result in a decrease in seawater pH, carbonate ion concentration [CO_3^{2-}], and saturation state with respect to calcium carbonate ($CaCO_3$) minerals, which are predicted to have negative effects on marine biomineralization [*Caldeira and Wickett*, 2003; *Doney et al.*, 2009]. This could negatively impact marine communities [*Sewell and Hofmann*, 2011] and alter global biogeochemical cycles [*Andersson*, 2014] for which biogenic carbonate mineral production and dissolution are important processes [*Milliman*, 1974; *Opdyke and Wilkinson*, 1993]. Marine biomineralization is the process by which pelagic and benthic organisms actively control and build $CaCO_3$ structures such as shells, tests, spines, and ossicles [e.g., *Lowenstam and Weiner*, 1989]. $CaCO_3$ in marine organisms occurs in various mineral forms or polymorphs, including the following: calcite, aragonite, Mg-calcite, and vaterite. Many benthic calcifiers use amorphous $CaCO_3$ as a transient phase in mineralization, which has radically different properties than its corresponding crystal polymorphs [*Raz et al.*, 2000, 2003]. The mineral composition of biogenic $CaCO_3$ is influenced by phylogeny and a number of external factors including temperature, salinity, light, seawater Mg/Ca ratio, seawater carbonate chemistry, life stage, and food supply, which also control growth rate [*Mackenzie et al.*, 1983; *Borremans et al.*, 2009; *Ries et al.*, 2009; *Ries*, 2010].

Despite environmental effects, calcifying organisms exert strong controls on the construction and maintenance of calcareous structures through a wide range of mechanisms, although the extent of control is related to the organism's specific mode of biomineralization and its energetic status [*Lowenstam and Weiner*, 1989]. For example, many calcifiers have specific ion pumps that aid in creating favorable chemical conditions for $CaCO_3$ deposition (e.g., H^+ pumps and HCO_3^- transporters) [*Zoccola et al*., 2015] and also deposit organic matrices that regulate sites of crystal nucleation and growth [e.g., *Lowenstam and Weiner*, 1989; *Dove et al*., 2003; *Tambutté et al*., 2011]. Recently, it has been proposed that seawater hydrogen ion concentration [H^+] plays a critical role affecting calcifiers ability to construct new $CaCO_3$ [e.g., *Jokiel*, 2011, 2013; *Ries*, 2011a], but it is equally important to consider the susceptibility of marine organisms' specific calcareous minerals to decreasing seawater $CaCO_3$ saturation state. For example, partial skeletal dissolution and/or weaker calcareous structures could render calcifying organisms more vulnerable to predation and/or increase the energetic demands of biomineralization [*Findlay et al*., 2011].

The seawater saturation state with respect to calcareous mineral phases (i.e., Mg-calcite) is defined as follows:

$$\Omega_i = \{Mg^{2+}\}^x \{Ca^{2+}\}^{(1-x)} \{CO_3^{2-}\} / IAP_i, \quad (1)$$

where i is the mineralogy (e.g., calcite, aragonite, and Mg-calcite), x is the skeletal mole fraction of $MgCO_3$ (if present), and IAP_i is the ion activity product at equilibrium with respect to the specific mineral phase [see *Morse et al*., 2006, and references therein]. Ω_i is important because it governs, on the basis of equilibrium thermodynamic principles, whether net formation ($\Omega_i > 1$) or dissolution ($\Omega_i < 1$) of $CaCO_3$ is favored and influences the relative rate at which these reactions proceed.

Many benthic calcite-producing organisms actively incorporate significant amounts of Mg^{2+} into their shells and skeletons during biomineralization (i.e., Mg-calcite). Mg-calcite with greater than 8–12 mol % $MgCO_3$ is more soluble than both pure calcite and aragonite [*Morse et al*., 2006]. Consequently, it has been hypothesized that organisms with Mg-calcite structures exceeding these mole % $MgCO_3$ values could be the most vulnerable to ocean acidification [*Morse et al*., 2006; *Andersson et al*., 2008]. Some experimental results support this hypothesis and show that skeletal mineral solubility impacts calcifiers' relative susceptibility to ocean acidification [*Kuffner et al*., 2008; *Martin and Gattuso*, 2009] while others do not [*Kroeker et al*., 2010; *Thomsen et al*., 2010; *Collard et al*., 2015]. In an experiment that investigated the impact of ocean acidification on 18 species of marine calcifiers spanning a range of $CaCO_3$ polymorphs [*Ries et al*., 2009], five of the six species that exhibited net dissolution under the highest-CO_2 treatment produced a skeleton from the relatively more soluble aragonite and high Mg-calcite polymorphs of $CaCO_3$, rather than from the less soluble low Mg-calcite polymorph. In addition to skeletal mineralogy, important factors that influence the susceptibility of organisms to ocean acidification include the following: the degree to which the organism's biomineral is protected by organic coatings, its ability to regulate pH and carbonate chemistry at the calcification site, its ability to utilize CO_2 via photosynthesis, the shell microstructure, life history, nutritional status, and the physiological condition of the organism [*Kuffner et al*., 2007; *Martin and Gattuso*, 2009; *Ries et al*., 2009; *Holcomb et al*., 2010; *Kroeker et al*., 2010; *Andersson and Mackenzie*, 2011].

Benthic Mg-calcite-secreting organisms, such as echinoderms, coralline algae, and crustaceans, dominate many coastal areas, continental shelves, slopes, and abyssal plains at all depths, and serve important ecosystem and biogeochemical functions, including food supply, ecosystem engineering, carbon storage and export, and elemental cycling [*Lebrato et al*., 2010; *Meadows et al*., 2012; *Andersson*, 2014]. Most studies to date do not consider species-specific seawater mineral saturation state on evaluating organisms' vulnerability to ocean acidification but have interpreted undersaturation with respect to aragonite or calcite as a critical threshold or "tipping point", regardless of organisms' mineral composition [*McNeil and Matear*, 2008; *Steinacher et al*., 2009; *Yamamoto-Kawai et al*., 2009; *Kroeker et al*., 2010; *Comeau et al*., 2013; *Dorey et al*., 2013]. This leads to an incomplete understanding of the influence of seawater carbonate saturation state and the potential consequences of ocean acidification on benthic marine calcifiers and the biogeochemical cycles in which they participate.

In this study, a global dataset of marine $CaCO_3$-producing organisms was collected from the field and from existing literature. Their biomineral compositions were then analyzed (field specimens) or compiled from published studies. Species-specific seawater Ω_i, based upon in situ seawater environmental data, were then calculated for these specimens and then used to model future seawater Ω_i. The objectives of

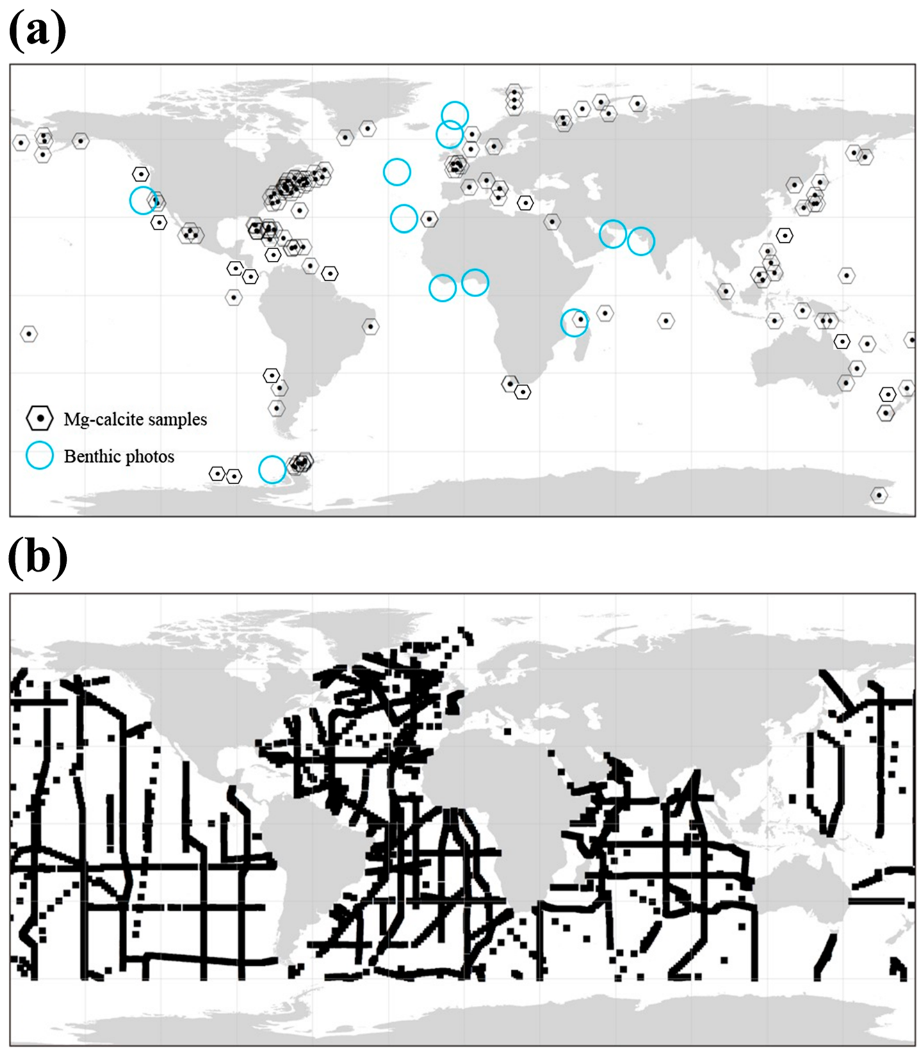

Figure 1. Sample maps. (a) Sample and photo locations. (b) Global coverage of temperature, salinity, and [CO_3^{2-}] data used to obtain the nearest value, in relation to organismal location, for calculating species-specific Ω_i (NEAR 3-D).

the study were to (1) characterize the range of mineralogies of benthic Mg-calcite organisms living in the intertidal/subtidal, neritic zones, continental shelves, slopes, and abyssal plains around the world; (2) determine under what species-specific seawater Ω_i conditions these organisms and mineral phases currently exist; and (3) explore how these conditions could change as a result of future ocean acidification predicted for the next several hundred years. The results of this study have broad implications for the way that seawater saturation state with respect to a particular carbonate mineral phase (Ω_i) is calculated and applied in marine science disciplines and for predicting the impacts of ocean acidification on marine calcifiers.

2. Materials and Methods

The organismal data used in this study were compiled from existing literature at the species level. A large number of echinoderm species were also collected from around the world and analyzed for their Mg content (Figure 1). The best approximation of in situ environmental and carbonate chemistry conditions was retrieved for each sample location based on the GLODAP and WAVES databases [*Key et al.*, 2004]. Details on literature mining, data classification, data analysis, and modeling are provided below. Detailed calculations and technical considerations involved in the calculation of seawater saturation state and solubilities for Mg-calcite (Tables S1 and S2 and Figures S1–S5 in the supporting information), additional information about the distribution of organismal and environmental samples (Tables S1 and S2 and Figures 1 and S2), the numerical modeling of the [CO_3^{2-}] reduction scenarios (Figure S4), and the master dataset (Tables S1–S4) are provided in the Supporting Information (SI).

2.1. Literature-Based Mg-Calcite Data

All measurements of mole % $MgCO_3$ of the investigated taxa and species (with the exception of the echinoderms, which were analyzed as part of the present study) were mined from the existing literature to generate the most comprehensive and taxonomically broad Mg-calcite dataset presently available (Figure 1 and Tables S1–S3). Most of the literature-based mole % $MgCO_3$ data were determined by powder X-ray diffraction and/or single collector inductively coupled plasma–mass spectrometry (ICP-MS) (Tables S2–4). The selection criteria for data derived from the literature was that (i) the organism was identifiable at the species level, (ii) weight % (wt %) or mole % $MgCO_3$ were measured, and (iii) reliable geographic and depth information were provided to link the species mole % $MgCO_3$ with the seawater conditions for each sample location. These data permitted calculation of species-specific seawater mineral saturation states. The following taxa, identified at the species level were assessed in the present study (see Tables S1–S4 for additional taxonomic and identifying information): Echinodermata—Asteroidea (49 species), Echinoidea (34 species), Ophiuroidea (23 species), and Crinoidea (21 species); Rhodophyta—Corallinaceae (26 species); benthic Foraminifera (12 species); Anthozoa—Hydrocorallia (3 species), Hexacorallia (12), and Octocorallia (35 species); Bryozoa (10 species); Brachiopoda (8 species); Mollusca—Amphineura (1 species), Bivalvia (7 species), Cephalopoda (3 species), Gastropoda (6 species), and Scaphopoda (1 species); and Crustacea—Cirripedia (5 species), Amphipoda (1 species), Decapoda (8 species), Stomatopoda (1 species), and Isopoda (1 species).

2.2. Skeletal Mg-Calcite Measurements

Skeletal mole % $MgCO_3$ data for the echinoderms were obtained through ICP-MS analysis of field-collected samples (Figure 1 and Tables S1–S4). Adult echinoderms were collected between years 2008 and 2011 from 2 to 1300 m depth in the Atlantic, Pacific, Arctic, and Southern Oceans (methods detailed in *Lebrato et al*. [2010] and *McClintock et al*. [2011]) (Tables S1 and S3). Note that these new analyses are unrelated to *Lebrato et al*. [2010], where "whole bodies" were measured to determine total carbon content. Here only skeletal material without associated organic material was analyzed. Samples were stored at −20°C in ziplock bags, freeze-dried for 48 h, and finally ground to powder. Percent $MgCO_3$ was measured with a Varian 820 inductively coupled plasma–mass spectrometer (ICP-MS) at the University of North Carolina at Chapel Hill (USA). A 0.5 g sample of pulverized material was digested for 2 h in *Aqua Regia* at 90°C. Duplicate samples were run every 15 samples, and in-house secondary standards were run every 33 samples. Certified standards and blanks were run every 68 samples. Antarctic samples were analyzed at Actlabs in Ancaster, Ontario, Canada (methods described in *McClintock et al*. [2011]). In brief, frozen samples were thawed and dissected and then soaked in 10% NaClO to remove organic matter. The remaining carbonate was vacuumed onto filter paper, rinsed with Milli-Q water, and then dried at 50°C for 48 h. Percent $MgCO_3$ was obtained using a PerkinElmer inductively coupled plasma (ICP) atomic emission spectrometer. The samples were divided in 90 to 500 mg splits and dissolved in nitric acid (HNO_3) and hydrochloric acid (HCl) in a molar ratio of 1:3 for 2 h at 95°C. Several U.S. Geological Survey standards were analyzed every 13 samples. Quality control results of the ICP-MS work are summarized in Table S4.

2.3. Linking Mg-Calcite Measurements to In Situ Physical and Chemical Data

Each organismal sample and their corresponding mole % $MgCO_3$ (either mined from the literature or measured directly) was associated with a latitude, longitude, and depth, allowing compilation of approximate in situ temperature, salinity, and carbonate chemistry data for each specimen (Table S2 and Figures 1 and S2). These environmental properties were extracted to the nearest value in a 3-D matrix in the GLODAP dataset [*Key et al*., 2004] using gridded station data from GLODAP/WAVES (http://cdiac3.ornl.gov/waves/discrete/) at a global scale. A regional dataset in the North Atlantic Ocean [*Dumousseaud et al*., 2010] was used to study temporal changes in Mg-content of calcite and Ω_i (Figure S5; see SI for details on how [CO_3^{2-}] was calculated). These databases were used because they contain the most complete and accurate seawater carbonate chemistry data currently available for the purpose of the present study.

It is important to note that the field data may not represent the exact in situ conditions experienced by the organisms and do not account for variability owing to oceanographic and seasonal processes. The calculations represent temporal "snapshots", with the actual species-specific seawater $\Omega_{Mg\text{-}x}$ varying throughout the year following environmental parameters that are discussed below (e.g., Figure 2). However, the variability in physical and chemical conditions at the depths considered here (seafloor) is substantially smaller than that experienced in the surface mixed layer. Also, the amplitude of seasonal variation is dampened as a function of decreasing latitude and increasing water depth.

ArcGIS 10.0 [*Environmental Systems Research Institute*, 2011] and the 3-D analytical tool "NEAR 3-D analysis" were used to link environmental seawater conditions with the organisms' parameters and mole % $MgCO_3$. This approach permitted evaluation of the diagonal distance between each organismal input parameter (latitude, longitude, and depth) and the nearest seawater datum (temperature (T), salinity (S), and [CO_3^{2-}]) at a specific latitude, longitude, and depth. The the prerequisite for data adoption was a matching data set *XYZ* (including organismal parameter) versus $X_iY_iZ_i$ (including ambient seawater property). Both data sets were plotted on a 2-D field and merged into a single 3-D field, and then the nearest seawater datum to the specimen was determined using a diagonal line in a 3-D matrix (Table S2). Additionally, each datum was individually checked to verify that the NEAR 3-D approach worked correctly. When the prediction was not sufficiently accurate, the closest value was manually selected. This procedure ensured selection of the most relevant seawater parameters for a given biological specimen.

2.4. Seawater Ω_i Calculations

Seawater saturation state with respect to calcite, aragonite, and calcite of a given mole % $MgCO_3$ ($\Omega_{Mg\text{-}x}$) was calculated according to equation (1). Detailed calculations, equations, constants, and corrections for temperature, salinity, and hydrostatic pressure used for calculations of seawater Ω_i with respect to all carbonate mineralogies in this study are available in the SI. Corrections for the influence of temperature and pressure on solubility were made in a manner similar to the correction of calcite solubility. This allows detailed seawater Ω_i approximations calcite of any Mg-content, thus going beyond the standard surface ocean conditions (e.g., total alkalinity, dissolved inorganic carbon, pH, temperature of 25 °C, salinity of 35) that are typically considered in calculating seawater Ω_i for calcareous organisms [*Morse et al.*, 2006; *Andersson et al.*, 2008; *Lavigne et al.*, 2011, Seacarb software]. This approach represents a new method to approximate seawater Ω_i for Mg-calcite bearing organisms at any temperature, salinity, and pressure (depth). The corresponding equations are provided in an *Excel* spreadsheet, available from the corresponding author upon request.

Individual ion activity products (IAP_i) employed in the $\Omega_{Mg\text{-}x}$ calculations were based on the biogenic "clean" and biogenic "minimally prepared" experimental solubility curves (Figure S1) [*Plummer and Mackenzie*, 1974; *Bischoff et al.*, 1987]. The two curves differ in the way that the experimental materials were prepared. Although there is currently insufficient information to determine which experimental solubility curve best represents the solubility of Mg-calcite mineral phases in the natural environment, several studies support the use of the minimally prepared solubility curve because it appears more compatible with complementary field and experimental results [*Tribble et al.*, 1995; *Andersson et al.*, 2007]. Therefore, results are presented that employ both solubility curves, with discussion focused on results derived using the minimally prepared solubility curves (Figure S1).

2.5. Photographic Evidence for Calcifying Organisms Inhabiting Undersaturated Seawater

As a complement to the quantitative aspect of this study, photographs of benthic Mg-calcite organisms at shelf, slope, rise, and abyssal depths in the Atlantic, Pacific, Indian, and Southern Oceans were obtained and analyzed to verify that Mg-calcite organisms live in waters from 0 to 5600 m and at $\Omega_{Mg\text{-}x}$ values near or below 1 (Table S5). The photographs were obtained using video cameras mounted on remotely operated or autonomous underwater vehicles, towed cameras, sled cameras, and still cameras [*Lebrato and Jones*, 2009; *Eastman et al.*, 2013] (Table S5).

Each photograph was associated with a location (latitude, longitude, and depth) and environmental data (T, S) obtained during the corresponding expedition (Table S5). If in situ T and S data were not available, data were compiled along with in situ [CO_3^{2-}] using the previously described ArcGIS NEAR 3-D analysis technique (including the manual check). Values of $\Omega_{Mg\text{-}x}$ were calculated for each organism at each location based on mean skeletal mole % $MgCO_3$ for the same species (when available), a similar species in the same class, or for the geographically closest species available (according to latitude and depth; see Table S5 for assumptions and data used). Although these qualitative data should be interpreted with caution, as organismal mineralogy is complex and highly variable, this approach yields insight into the distribution of $\Omega_{Mg\text{-}x}$ for benthic marine calcifiers in the deep-sea (2000 to 5600 m). It should also be noted that the photos presented in Figure 6

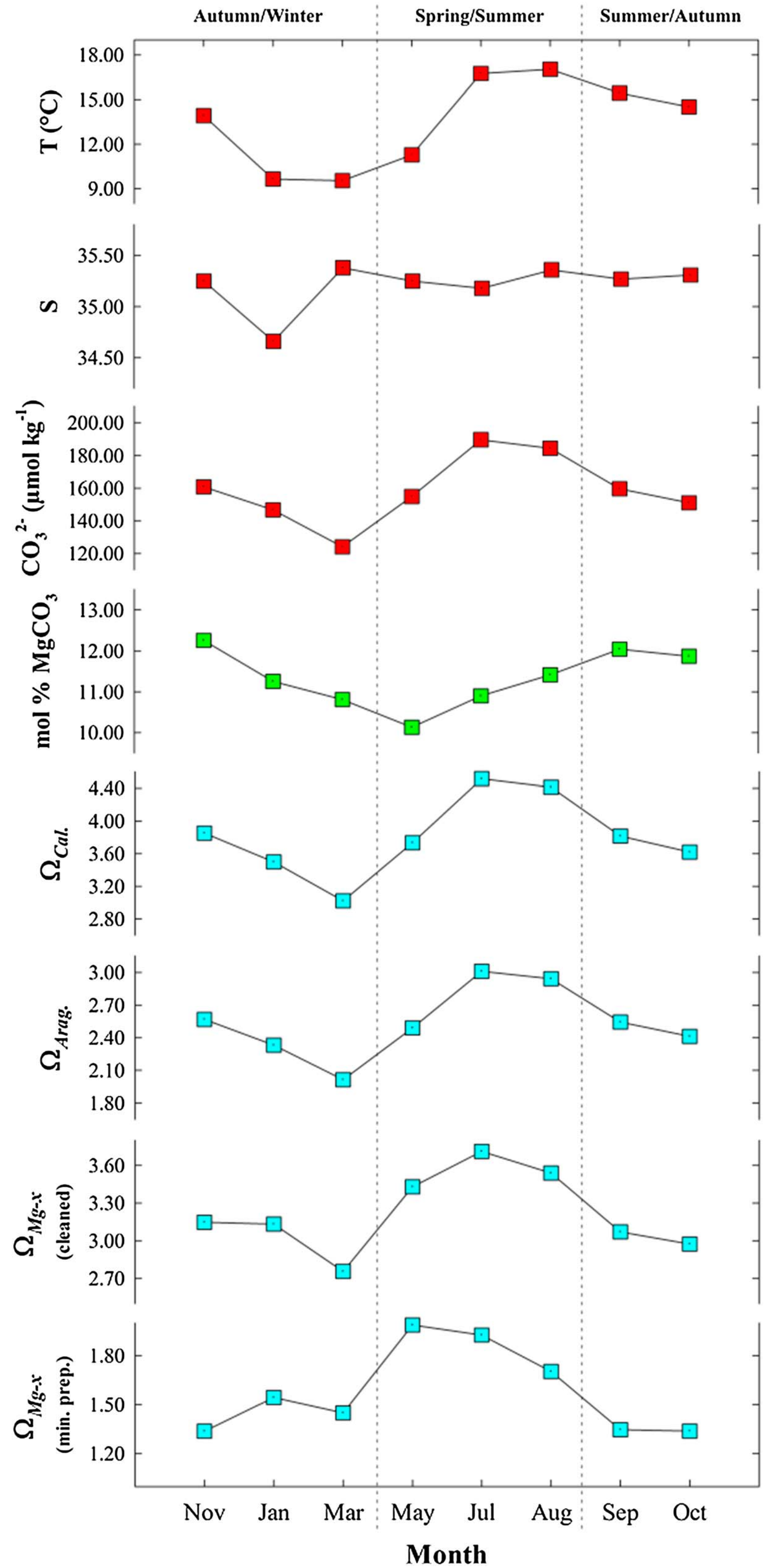

Figure 2. Seasonal changes in the skeletal mole % $MgCO_3$ in the coralline alga *Corallina squamata*. The coralline Mg-calcite samples were obtained over 11 months at 5 m on the Dorset coast (UK, Atlantic Ocean) [*Haas et al.*, 1935]. Calculated seawater Ω_i is plotted over time, with seasonal variations in skeletal mole % $MgCO_3$ driven by seasonal variability in seawater temperature.

represent only a small subset of all images used in this analysis. However, all sampling locations for which photographs were obtained are plotted in Figure 6, with corresponding data provided in Table S5.

2.6. Modeling of [CO_3^{2-}] Decrease to Predict Future Ω_i

In order to better understand how oceanic Ω_i will change in the future in response to increasing pCO_2 and temperature, [CO_3^{2-}] was calculated for surface and bottom waters at future time points using the UVic Earth System Model [*Keller et al*., 2012] (Figure S4). CO_2 emissions were forced with the Representative Concentration Pathway 8.5 scenario, which is a "business-as-usual", high-CO_2-emission scenario [*Keller et al*., 2014]. Decreases in [CO_3^{2-}] of 20 and 50% from modern values were used to estimate the timing of these scenarios for the surface and seafloor (−20% sfc: 2050–2065; −20% sfl: 2150–2700; −50% sfc: 2090–2120; −50% sfl: 2500–3000+; white areas in the figure maps are beyond year 3000; Figure S4). The output represents the globally averaged change in [CO_3^{2-}] over time for surface and bottom waters. The years provide an approximation of this change because [CO_3^{2-}] in deeper water masses decline at a slower rate than in surface waters (see Figures 4 and S4). The model projections include the impact of anthropogenic CO_2 invasion as well as the effect of increasing ocean temperature on this process.

3. Results

3.1. Percent $MgCO_3$ of organisms' Mg-Calcite

The Mg content of the organisms in the global dataset ranged from < 1 to > 27 mole % $MgCO_3$, varying significantly among and within phyla, classes, and species (Figure 3a). The lowest mean mole % $MgCO_3$ content was observed in the class Anthozoa (Hydrocorallia and Hexacorallia) and phylum Mollusca (Bivalvia, Amphineura, Scapopoda, and Gastropoda) with a mean [±SD (standard deviation)] of 1.96 ± 3.80 and 1.27 ± 1.33 mol % $MgCO_3$, respectively. The highest mole % $MgCO_3$ was observed in the Rhodophyta (coralline algae, mainly Corallinaceae) with a mean (±SD) of 16.29 ± 5.02 mol % $MgCO_3$, but this phylum also showed the greatest range from 7.11 to 27.27 mol % $MgCO_3$. Large variability was also observed within Echinodermata (Classes Asteroidea, Echinodea, Ophiuroidea, and Crinoidea), Protista (Foraminifera), Anthozoa (Octocorallia), Bryozoa, Mollusca (Cephalopda), and Crustacea (Decapoda), ranging from 0.40 to 18.14 mol % $MgCO_3$ (Figure 3a).

In general, the Mg content of organisms with greater than 5 mol % $MgCO_3$ followed an inverse parabolic distribution as a function of latitude, with decreasing Mg content toward the poles (Figure 3b). In contrast, organisms with less than 5 mol % $MgCO_3$ showed no apparent trend as a function of latitude. Considering Mg content as a function of depth, large variability was observed between 0 and 200 m (0.19 to 27.26 mol % $MgCO_3$), there were almost no occurrences of organisms with greater than 16 mol % $MgCO_3$ between 100 and 200 m, and there were no organisms with greater than 9 mol % $MgCO_3$ below 600 m (Figure 3c). Organisms containing less than 5 mol % $MgCO_3$ were mainly observed between 0 and 100 m, with a few observations at 700 m. The rare occurrence of organisms with < 5 mol % $MgCO_3$, compared to organisms with a higher Mg content, at depths greater than 100 m is puzzling and raises questions about whether this reflects a true biological pattern or is simply a sampling artifact. Similarly, measurements of mole % $MgCO_3$ of organisms collected from depths greater than 1000 m were uncommon in the literature (only seven samples from 1000 to 4000 m, excluding the photo analysis), although there is ample evidence that Mg-calcite-producing organisms exist at these depths [*Sokolova*, 1972; *Gage and Tyler*, 1991].

3.2. Species-Specific Seawater Ω_i Under Present Conditions in Benthic Habitats

Seawater saturation states with respect to calcite ($\Omega_{Cal.}$) and aragonite ($\Omega_{Arag.}$) exhibited an inverse parabolic relationship from pole-to-pole at all depths (i.e., lower seawater saturation at high latitudes), with $\Omega_{Cal.}$ ranging from 1.1 to 7.7 and $\Omega_{Arag.}$ ranging from 0.7 to 5.1 from high to low latitudes (Figure 4; 0.3% to 1.5% of locations were less than 1 with respect to $\Omega_{Cal.}$ and $\Omega_{Arag.}$, respectively). In general, the location-specific seawater $\Omega_{Cal.}$ and $\Omega_{Arag.}$ decreased with depth, a trend driven by decreasing [CO_3^{2-}] related to increasing respiratory CO_2 in the water masses, and increasing solubility owing to increasing pressure and decreasing temperature (Figure 5). In contrast, at depths <200 m, seawater $\Omega_{Cal.}$ and $\Omega_{Arag.}$ ranged from 2.1 to 7.7 and from 1.4 to 5.1, respectively, with the broad range resulting from the large temperature variation (−0.86 to 39.38°C) as a function of latitude (Table S1 and Figure 5). For depths greater than 1000 m, seawater $\Omega_{Cal.}$ and $\Omega_{Arag.}$ were always below 2 (except in one case), with most values very near or below 1 (Figures 5 and 6).

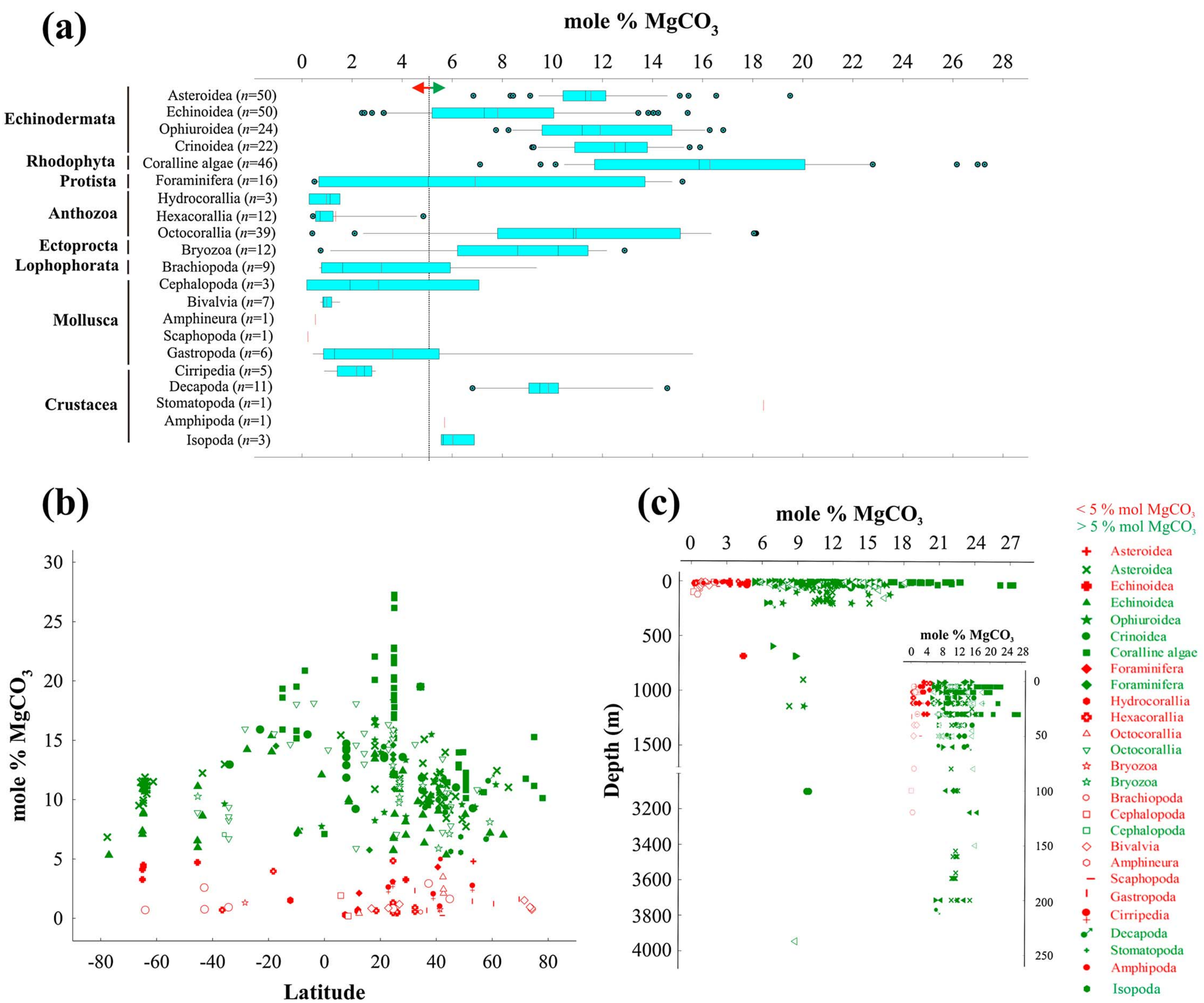

Figure 3. Patterns of Mg-calcite skeletal mineralogy. (a) Box plots of skeletal mole % $MgCO_3$ of all taxa investigated in this study (n = sample size for each taxon), including minimum and maximum values (box edges), outliers (circles), and the mean value (red line inside the boxes). The vertical black dotted line in Figure 3a represents 5 mol % $MgCO_3$ (Figure 3b; red = <5 mol % $MgCO_3$; green = >5 mol % $MgCO_3$). Also included are trends of skeletal mole % $MgCO_3$ by (b) latitude and (c) depth. See Tables S1–S3 for additional information about skeletal/shell mineralogy.

If one were to consider seawater $\Omega_{Mg\text{-}x}$ for any specific Mg-calcite phase (e.g., 15 mole % $MgCO_3$), the shape of the $\Omega_{Mg\text{-}x}$ latitudinal trend would be similar to trends observed for aragonite and calcite (Figures S3d and S3e). Considering the species-specific seawater $\Omega_{Mg\text{-}x}$ for these samples, however, there were no obvious latitudinal trends due to the differing mineralogies (solubilities), temperatures, and depths (pressure and $[CO_3^{2-}]$ effects; Figures 3–5, Table S1, and Figures S2 and S3). For Mg-calcite containing < 5 mole % $MgCO_3$, the species-specific $\Omega_{Mg\text{-}x}$ ranged from 2.1 to 6.8 at depths less than 1000 m, with no obvious trend toward higher latitudes. For Mg-calcite containing > 5 mol % $MgCO_3$, the species-specific $\Omega_{Mg\text{-}x}$ ranged from 0.3 to 5.8 at depths less than 1000 m. A total of 24.1% of the species were exposed to seawater $\Omega_{Mg\text{-}x} < 1$ across all studied latitudes and depths. Although there was no clear trend of seawater $\Omega_{Mg\text{-}x}$ with latitude, a greater proportion of the low-latitude species were found inhabiting undersaturated conditions (22.1% were exposed to seawater $\Omega_{Mg\text{-}x} < 1$; Figures 4 and 5 bottom panels) when compared with the

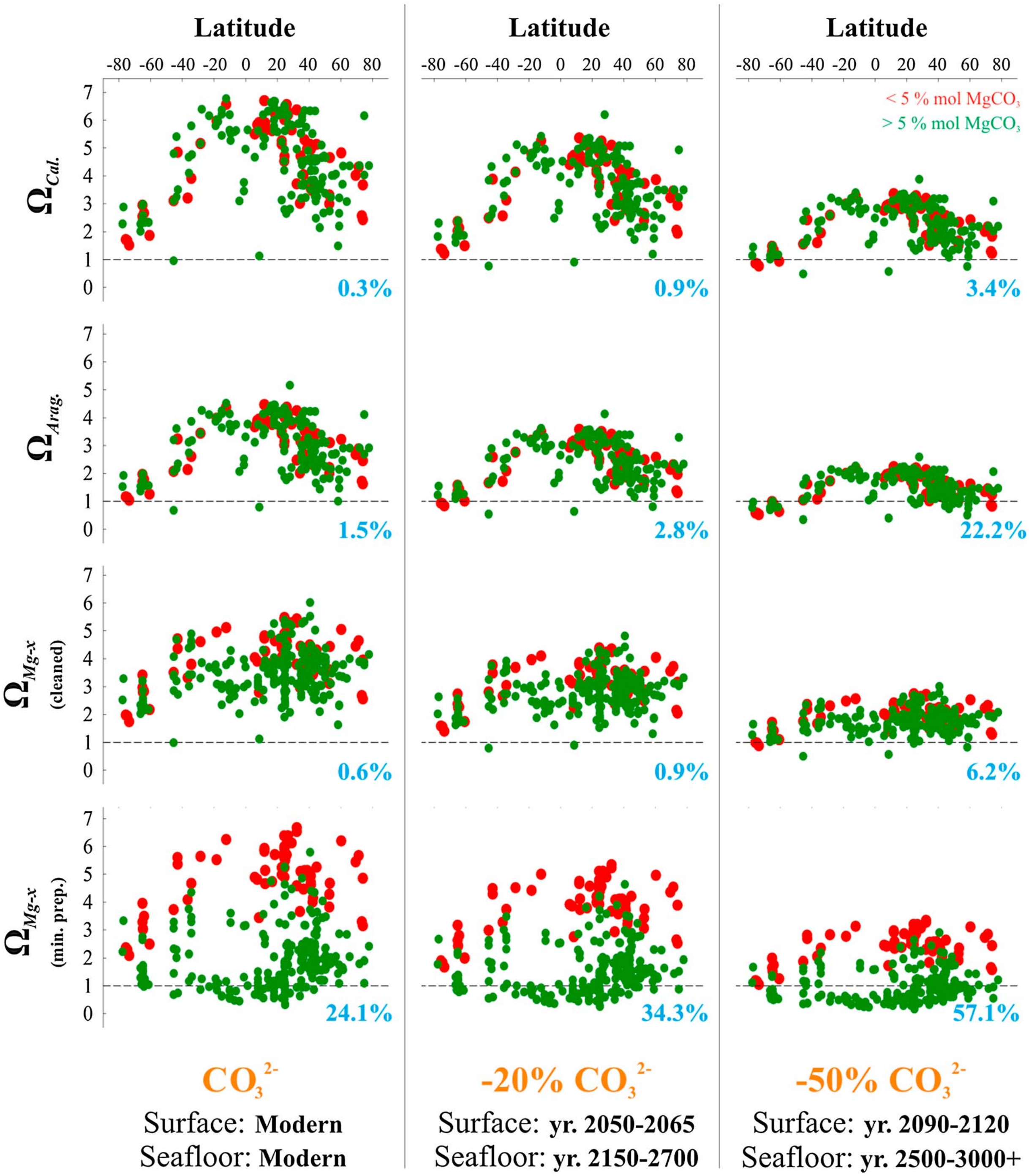

Figure 4. Calcite, aragonite, and taxon-specific seawater-Ω_i patterns versus latitude. Seawater-Ω_i is calculated using the organisms' skeletal mole % $MgCO_3$ and their in situ seawater conditions in the modern and future ocean, with [CO_3^{2-}] reduced by 20% in years 2050–2065 (surface) and 2150–2700 (seafloor), and by 50% in years 2090–2120 (surface) and 2500–3000+ (seafloor). The dotted lines represent equilibrium Ω_i (i.e., $\Omega_i = 1$), below which mineral dissolution theoretically begins pursuant to the principals of equilibrium thermodynamics. The percentages of taxa living in undersaturated conditions with respect to their species-specific mineralogies (i.e., $\Omega_i < 1$) are shown in blue.

high-latitude species (2%). The highest proportion of species exposed to undersaturation was observed at depths <2000 m, and especially at depths <200 m in the coastal zones (Figure 4). Seawater undersaturation for most species appears to extend from depths of 2000 to 5600 m (90% of the taxa at these depths; Figures 3 and 4). The range of values for species-specific seawater $\Omega_{Mg\text{-}x}$ decreased as a function of depth.

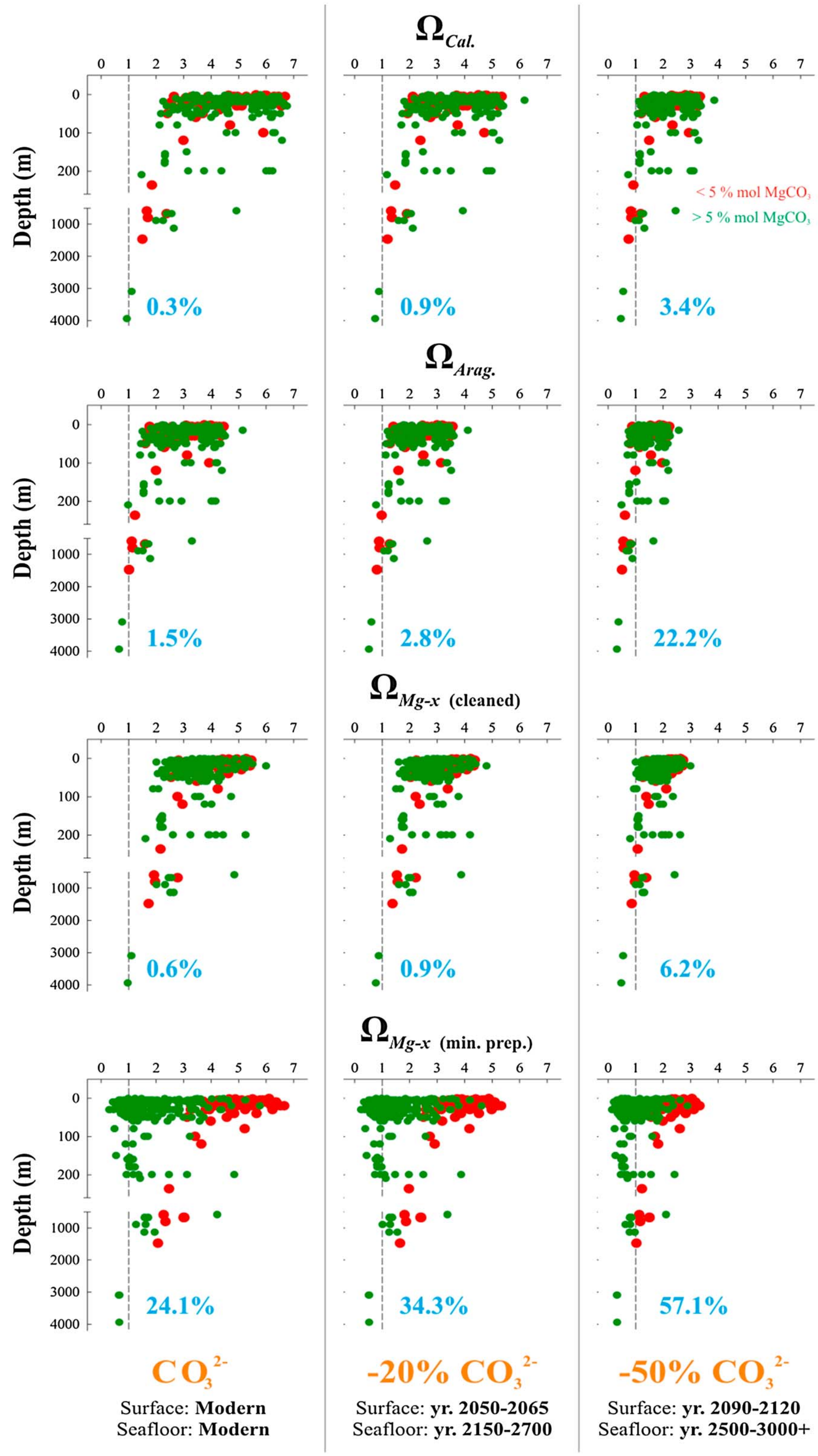

Figure 5. Taxon-specific seawater-Ω_i patterns versus depth. Seawater-Ω_i is calculated using the organisms' ambient seawater conditions and the skeletal mole % $MgCO_3$ in the modern and future ocean, with [CO_3^{2-}] reduced by 20% in years 2050–2065 (surface) and 2150–2700 (seafloor), and by 50% in years 2090–2120 (surface) and 2500–3000+ (seafloor). The dotted lines represent equilibrium Ω_i (i.e., $\Omega_i = 1$), below which mineral dissolution theoretically begins pursuant to the principals of equilibrium thermodynamics. The percentages of taxa living in undersaturated conditions with respect to their species-specific mineralogies (i.e., $\Omega_i < 1$) are shown in blue.

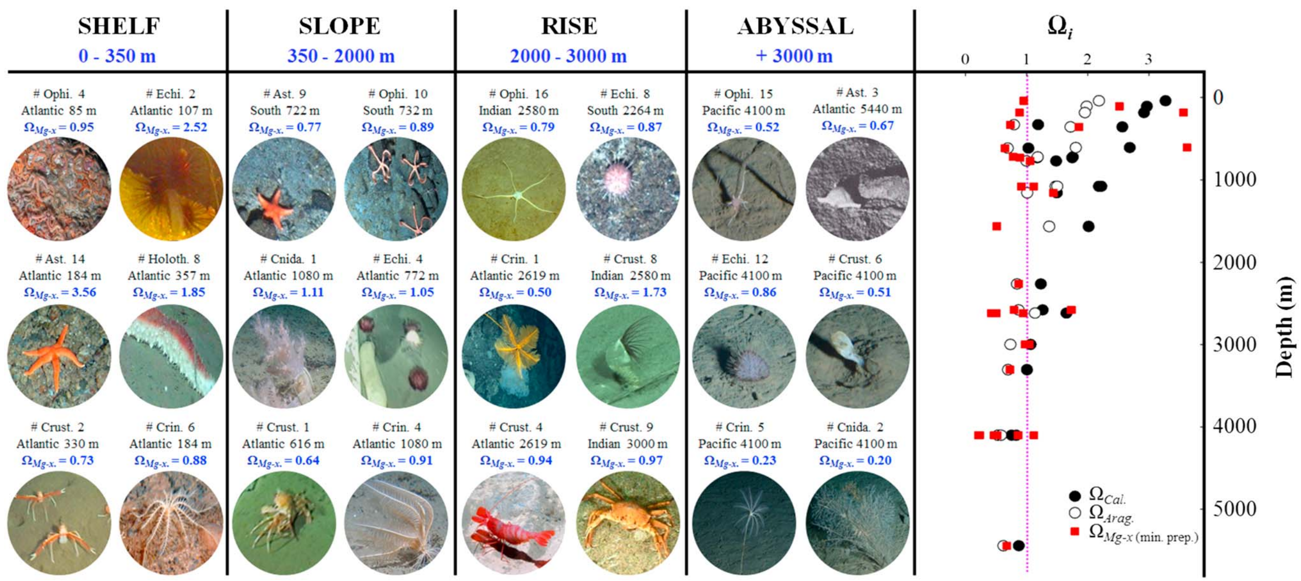

Figure 6. Calcareous organisms at shelf, slope, rise, and abyssal plain (Ophi: Ophiuroidea, Echi: Echinoidea, Ast: Asteroidea, Holoth: Holothuroidea, Cnida: Cnidaria, Crin: Crinoidea, Crust: Crustacea; see Table S5 for all species). Composite photographs from the Atlantic, Pacific, Indian, and Southern Oceans from 0 to 5600 m depth in the modern ocean (complete results in Table S5). In situ $\Omega_{\text{Mg-}x}$ was calculated using Mg content of the specimen imaged in the photograph. For photos lacking physical specimens, in situ $\Omega_{\text{Mg-}x}$ was calculated using mean Mg content of other individuals of the same species (when available), of the closest available species (according to latitude and depth), or of other species within the same class. In situ seawater parameters were obtained from a NEAR 3-D analysis (see section 2). Ambient seawater conditions along with calculated seawater pH_{total} and CO_2 are presented in Table S5. The plot on the right side shows the calculated seawater Ω_i profiles for all specimens (calcite, aragonite, and Mg-calcite) with depth, revealing that most higher Mg-calcite-producing organisms are inhabiting seawater that is undersaturated with respect to their shell mineralogy across all four facies (shelf, slope, rise, abyssal plain). Pink dotted line represents equilibrium Ω_i (i.e., $\Omega_i = 1$), below which mineral dissolution theoretically begins pursuant to the principals of equilibrium thermodynamics. Data represent modern ocean conditions.

3.3. Species-Specific Seawater Saturation States Under Future Conditions in Benthic Habitats

To project species-specific $\Omega_{Mg\text{-}x}$ into the future, two scenarios anticipated for years 2050–2065 (surface)/2150–2700 (seafloor) and 2090–2120 (surface)/2500–3000+ (seafloor) were assessed. In these scenarios, the general trends of seawater Ω_i with respect to calcite, aragonite, and Mg-calcite, remained the same as a function of latitude and depth compared with the present-day ocean, but at lower saturation states (Figures 4 and 5). In response to a 20% decrease in [CO_3^{2-}], almost all locations were supersaturated with respect to calcite, 2.8% were undersaturated with respect to aragonite, and 34.3% were undersaturated with respect to species-specific $\Omega_{Mg\text{-}x}$ across all studied latitudes and depths. A 50% reduction in [CO_3^{2-}] resulted in seawater undersaturation at 3.4% of locations for calcite, 22.2% for aragonite, and 57.1% for species-specific $\Omega_{Mg\text{-}x}$ across all studied latitudes and depths, with seawater undersaturation for all species between 2000 and 5600 m depth.

4. Discussion

At present, a surprisingly high proportion of benthic marine calcifying species (24.1% across all studied latitudes and depths, and 90% below 2000 m; Figures 5 and 6) are inhabiting seawater that is undersaturated with respect to their species-specific mineralogy, especially at low latitudes (equatorial). These taxa are primarily coralline algae, crinoids, and octocorals, with Mg content that is typically greater than 14 mol % $MgCO_3$, (Figure 4, bottom panels). High (polar) latitude oceans, in contrast, contain a lower proportion of species living in seawater undersaturated with respect to their species-specific mineralogies because their overall mole % $MgCO_3$ is lower than at tropical latitudes, although many appear to exist close to a metastable equilibrium with seawater (i.e., $\Omega_{Mg\text{-}x} = 1$). Given the relatively stable conditions in seawater carbonate chemistry experienced for hundreds of thousands of years prior to the Industrial Revolution [*Zeebe*, 2012], it appears that many organisms have been living at or below equilibrium ($\Omega_{Mg\text{-}x} \leq 1$) for an extended time. It can therefore be assumed that marine benthic calcifiers have long possessed physiological adaptations that allow them to build and maintain calcareous structured under such low $\Omega_{Mg\text{-}x}$ conditions. Other environmental properties (e.g., food availability) may also help or hinder organisms' ability to overcome negative effects of low seawater $\Omega_{Mg\text{-}x}$ in these environments.

Yet, the question remains as to how marine benthic calcifiers inhabiting seawater of $\Omega_{Mg\text{-}x} < 1$ maintain and build their calcareous structures, which based upon thermodynamic principles, should dissolve. Many benthic species have calcareous skeletons and/or shells that are covered with tissue and/or organic compounds while the organisms are alive (e.g., periostraca, epicuticles, and epiderma) that isolate and separate the Mg-calcite from seawater to protect the structures from dissolution [*Ries et al*., 2009]. The protective value of organic coatings is apparent after the organism dies, as unprotected shells and skeletons tend to dissolve rapidly [*McClintock et al*., 2009] and often do not become part of the sedimentary record in most modern marine environments (excluding carbonate platforms and coral reef environments). This is pronounced in polar waters and the deep sea, where seawater tends to be highly corrosive to carbonate minerals [*Waldbusser et al*., 2011; *Walker et al*., 2013]. Organisms that have access to a regular and adequate supply of energy via heterotrophy and/or photosynthesis are also more likely to overcome constraints imposed by low seawater $\Omega_{Mg\text{-}x}$ [*Sokolova*, 1972; *Holcomb et al*., 2010; *Smith et al*., 2013; *Castillo et al*., 2014]. For example, mollusks in the Kiel Fjord (Baltic Sea) thrive and spawn under chemically unfavorable conditions (very high CO_2) because these conditions coincide with a large, seasonal food supply connected to regional upwelling [*Thomsen et al*., 2010]. Similarly, the high energy available at low latitudes, due to higher irradiance and, thus, higher rates of photosynthesis, probably explain why many coralline algae with high Mg-calcite content (14 to 27 mol % $MgCO_3$) are able to thrive despite species-specific seawater undersaturation (Figures 3 and 4). Furthermore, organisms living in low $\Omega_{Mg\text{-}x}$ conditions may be able to reallocate energy to maintain calcification, but at the expense of other functions, such as growth, energy storage, and reproduction [*Wood et al*., 2008; *McCulloch et al*., 2012; *Dupont et al*., 2013]. Observations also suggest that deep-sea and some polar Mg-calcite organisms tend to have softer body structures and thinner skeletons than elsewhere, but it is unknown whether this is a consequence of hydrostatic pressure, low temperature, seawater carbonate chemistry, low predation, or any other factor or combination of factors [*Gage and Tyler*, 1991; *Aronson et al*., 2007; *Watson et al*., 2012] (Figure 6).

The observation that many marine calcifiers inhabit depths that are undersaturated with respect to their species-specific mineralogies (Figure 6 and Table S5) suggests that they are utilizing compensatory physiological mechanisms to cope with undersaturated conditions. The Mg content of shallow water coralline algal calcite varies on monthly timescales by up to 2 mol % (Figure 2) [*Haas et al*., 1935]. This translates to shifts in seawater $\Omega_{Mg\text{-}x}$ from 1.20 in November to 1.90 in February of the same year (and back to 1.20 in October) in coastal waters of the UK, corresponding to a greater than 50% change (Figure 2). Although these annual changes in Mg content should confer additional resilience during colder months of the year, it is presently unclear whether this is an active survival strategy or a passive thermodynamic or kinetic response to fluctuations in seawater temperature and [CO_3^{2-}].

Thermodynamic principles suggest that marine organisms require more energy to biocalcify under more acidic conditions. Thus, organisms' specific responses to ocean acidification should be dictated by their energy budgets and whether there are thresholds beyond which they cannot divert additional energy from other physiological functions without negative consequences to their overall fitness [*Dupont et al*., 2013]. It has also been shown that some marine calcifiers, such as whelks and coralline red algae, deposit increasingly stable mineral phases (decrease in Mg content) in response to ocean acidification (see also Figure 2 for temporal changes), while others (e.g., calcareous serpulid worms) deposit increasingly less stable mineral phases in response to ocean acidification, and still others (e.g., urchins, lobsters, crabs, and shrimp) show no mineralogical response to ocean acidification [*Ries*, 2011b].

As seawater $\Omega_{Mg\text{-}x}$ changes in benthic ecosystems as a function of depth and latitude, some organisms may adapt to ocean acidification by progressively migrating to nearby regions of higher seawater saturation state. For example, it was observed that 95% of all deep-sea corals live at depths above the aragonite saturation horizon [*Guinotte et al*., 2006]. Nonetheless, it is likely that some taxa will not be able to tolerate decreasing saturation states and could suffer significant mortality and population declines, as did certain benthic foraminifera during the Paleocene-Eocene Thermal Maximum ocean acidification event [*Hönisch et al*., 2012; *Clarkson et al*., 2015]. Calcareous organisms with $<$5 mol % $MgCO_3$ from the present dataset that inhabit depths shallower than 4000 m will remain in supersaturated seawater conditions even after a 50% decline in seawater [CO_3^{2-}] (Figures 4 and 5), potentially providing them with a competitive advantage over calcifiers with a higher mole % $MgCO_3$. Note though that seawater chemistry varies between the ocean basins and, in general, seawater $\Omega_i = 1$ occurs at a much shallower depth in the Pacific Ocean compared to the Indian and Atlantic Oceans [*Andersson*, 2014]. The present study shows that many shallow-water Mg-calcite organisms, and most deep-sea Mg-calcite organisms inhabiting waters deeper than 2000 m, already inhabit undersaturated seawater, suggesting that they have evolved the biological and physiological mechanisms needed to survive in seawater $\Omega_{Mg\text{-}x} \leq 1$. It should be emphasized, however, that it remains unknown how such deep-sea calcifiers will respond to the rapid declines in seawater $\Omega_{Mg\text{-}x}$ accompanying anthropogenic ocean acidification, as these organisms generally originated in environments when seawater saturation state was relatively stable, albeit low [*Gage and Tyler*, 1991].

To accurately predict the impacts of ocean acidification on benthic marine taxa and ecosystems, it is critical to determine whether there are thresholds or so-called tipping points (or points-of-no-return) in organisms' responses [*Hall-Spencer et al*., 2008]. Some studies have suggested $\Omega_{Arag.} = 1$ as a tipping point, but this value is not theoretically appropriate for taxa with skeletons that are more (or less) soluble than aragonite [*Feely et al*., 2004; *Hall-Spencer et al*., 2008; *McNeil and Matear*, 2008; *Steinacher et al*., 2009; *Yamamoto-Kawai et al*., 2009; *Kroeker et al*., 2010] (Figures 4–6 and S1 and S3). This study highlights the need to consider species-specific $\Omega_{Mg\text{-}x}$ in assessing tipping points in biological responses to ocean acidification.

Our ability to predict calcareous organisms' responses to ocean acidification is hindered by a poor understanding of the physiological controls on Mg incorporation into calcareous structures, especially in relation to changes in seawater [CO_3^{2-}]. We also have limited knowledge of the role that Mg incorporation plays in the formation and stabilization of amorphous calcium carbonate, which appears to be a transient phase in some modes of biological mineralization, and how this mineral phase is impacted by changes in seawater carbonate chemistry [*Raz et al*., 2000, 2003]. Experiments and field observations have indicated that Mg content in some taxa can change as a function of seawater [CO_3^{2-}] on monthly to seasonal timescales, although cause and effect remain elusive [*Haas et al*., 1935; *Agegian*, 1985; *Ries*, 2011b; *Williamson et al*., 2014] (Figure 2). Thus, it is important to recognize that fluctuations in some seawater carbonate system parameters, for example, on a seasonal basis, will increase as the buffering capacity of seawater decreases with ocean acidification [*Riebesell et al*., 2009; *Melzner et al*., 2013]. Predicting the effects of ocean acidification on biomineralization in Mg-calcite organisms and higher-level effects on benthic ecosystems requires a better understanding of how these organisms produce their shells and skeletons, how seawater $\Omega_{Mg\text{-}x}$ relates to organismal fitness, a reassessment of the solubility of biogenic Mg-calcite mineral phases, and a better understanding of the controls of Mg incorporation in calcareous biominerals.

5. Conclusion

The primary conclusions of the research are as follows:

1. The $\Omega_{Cal.}$ and $\Omega_{Arag.}$ are not appropriate estimates for the saturation state of seawater with respect to Mg-calcite biominerals because they do not account for the Mg content of the calcite, which will effectively increase its solubility. Thus, species-specific $\Omega_{Mg\text{-}x}$ should be calculated from that species' actual mole % $MgCO_3$, pursuant to the equation: $\Omega_{Mg\text{-}x} = \{Mg^{2+}\}^x\{Ca^{2+}\}^{(1\text{-}x)}\{CO_3{}^{2-}\}/IAP_i$, where x is the mole fraction of Mg in substitution for Ca in the calcite lattice.
2. The Mg content for a global compilation of calcite-producing benthic marine organisms increases from pole to equator (i.e., inverse parabolic pattern from pole-to-pole).
3. The calculated $\Omega_{Mg\text{-}x}$ for a global compilation of calcite-producing benthic marine organisms with skeletons containing $<$5 mol % $MgCO_3$ exhibits no systematic variation with latitude, while calculated $\Omega_{Mg\text{-}x}$ for calcifiers with $>$5 mol % $MgCO_3$ decreases from pole to equator (i.e., parabolic pattern from pole-to-pole).
4. At present, 24% of the studied calcite-producing benthic marine organisms experience seawater undersaturation ($\Omega_{Mg\text{-}x} < 1$) worldwide, with a surprisingly higher proportion in tropical waters (~95%) versus polar waters (~5%), apparently owing to the increasing trend in Mg content of biogenic calcite from pole to equator. Most deep-sea Mg-calcite-producing organisms ($>$1200 m) also experience seawater undersaturation under present-day pCO_2.
5. As a result of increasing pCO_2 and decreasing $[CO_3{}^{2-}]$ (by up to 50% over the next 3000 years), between 34 and 57% of the surveyed marine calcifiers (including all mineralogies) across all latitudes and depths will experience seawater undersaturation.

Future work should aim to empirically constrain the stoichiometric solubilities of biogenic Mg-calcite, the controls on Mg incorporation in biogenic calcite, seasonal and spatial variability of Mg in biogenic Mg-calcite, and the vulnerability of Mg-calcite-producing organisms to future ocean acidification and warming—the latter of which can now be informed by estimates of species-specific $\Omega_{Mg\text{-}x}$ established through the present contribution.

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Global Biogeochemicals Cycles

Supporting Information for

Benthic marine calcifiers coexist with $CaCO_3$-undersaturated seawater worldwide

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7. Supporting information

7.1 Full development of the seawater Ω_i calculations

The seawater saturation state with respect to calcareous mineral phases is defined as:

$$\Omega_i = \{Mg^{2+}\}^{x} \{Ca^{2+}\}^{(1-x)} \{CO_3^{2-}\} / IAP_i \quad \text{(Eq. 1)}$$

where *i* is the mineralogy (i.e., calcite, aragonite, Mg-calcite), *x* is the skeletal mol % $MgCO_3$ if present, and IAP_i is the ion activity product at equilibrium with respect to the specific mineral phase.

The ion activities ({}) of Mg^{2+}, Ca^{2+}, and CO_3^{2-} in Eq. 1 were calculated from the total activity coefficients of each ion [$\gamma_T(i)$], and the total concentration in seawater ($[i]_T$):

$$\{i\} = \gamma_T(i)\ [i]_T \quad \text{(Eq. 2)}$$

The $\gamma_T(i)$ is controlled by the seawater composition. Values were obtained from a chemical equilibrium model of seawater [Millero & Pierrot, 1998]. The equations used to work out $\gamma_T(i)$ from the corresponding field temperatures (in °C) for each data point and for each ion were:

$$\gamma_T(CO_3^{2-}) = 9*10^{-7}\ T^2 - 0.0004\ T + 0.0521 \quad \text{(Eq. 3)}$$

$$\gamma_T(Mg^{2+}) = -0.0008\ T + 0.2223 \quad \text{(Eq. 4)}$$

$$\gamma_T(Ca^{2+}) = -6*10^{-6}\ T^2 - 0.0002\ T + 0.2078 \quad \text{(Eq. 5)}$$

where T is the individual in situ field temperature at its corresponding depth obtained from the NEAR 3D analysis.

The field $[i]_T$ for Mg^{2+} and Ca^{2+} was calculated following the Marcet's Principle of seawater constant proportions following in situ salinity for each sample:

$$[Mg^{2+}]_T = (S\ 1.295/35.00) / 24.305 \quad \text{(Eq. 6)}$$

$$[Ca^{2+}]_T = (S\ 0.416/35.00) / 40.078 \quad \text{(Eq. 7)}$$

where S is the individual in situ field salinity at its corresponding depth.

The $[CO_3^{2-}]$ was calculated from in situ total alkalinity (TA) and dissolved inorganic carbon (DIC) measurements from the GLODAP and WAVES database http://cdiac3.ornl.gov/waves/discrete/ (Suppl. Fig. S6) along with the in situ temperature, salinity, and nutrients using the CO2SYS macro (Lewis & Wallace, 1998). The field $[i]_T$ was therefore:

$[CO_3^{2-}]_T$ = field input data from the NEAR 3D analysis and 20 and 50 % decrease for simulation of future ocean acidification scenarios, calculated in CO2SYS.

The 20 and 50 % decreases in $[CO_3^{2-}]$ from modern values to represent ocean acidification scenarios were estimated for years 2050-2065 (surface) and 2150-2700 (seafloor), and 2090-2120 (surface) and 2500-3000+ (seafloor), respectively, from a model run using the UVic Earth System Climate Model (Keller *et al.,* 2012) (Suppl. Fig. S4). Only the Representative Concentration Pathway (RCP) 8.5 climate change scenario was used, and the output represented the globally averaged change in $[CO_3^{2-}]$ over time for surface and seafloor waters. Bear in mind that for seafloor waters there is uncertainty about the exact years owing to the vertical model ressolution.

The Ion Activity Product (IAP_i) is the product of the ion activities at equilibrium determined at a condition originally referred to as stoichiometric saturation for Mg-calcite (Plummer & Mackenzie, 1974; Morse *et al.,* 2006). For calcite and aragonite we obtained the thermodynamic constants from published equations (Millero 1979; Morse & Mackenzie, 1990), and we corrected for in situ temperature (T). Constants were not corrected for salinity owing to its minor influence, and also because the salinity effect was corrected in the calculation of the field $[i]_T$ for Mg^{2+} and Ca^{2+}. The working equations are:

$$-\log IAP_{Cal.}(T) = 303.1308 + (-13348.09/T) + (-48.7537 \ln T) \qquad \text{(Eq. 8)}$$

$$-\log IAP_{Arag.} (T) = 303.5363 + (-13348.09/T) + (-48.7537 \ln T) \quad \text{(Eq. 9)}$$

where individual temperature (T) is in kelvin (°K). IAPs were taken from the corresponding anti-logs.

The individual IAP_i for each organism condition was corrected for the pressure effect using published equations [Millero, 1979; Ingle, 1975; Millero, 1995]:

Calcite:

$$\mathit{delta}VK_{Cal.} = -48.76 + 0.5304\ T_{°C} \quad \text{(Eq. 10)}$$

$$\mathit{kappa}K_{Cal.} = (-11.76 + 0.3692\ T_{°C}) / 1000 \quad \text{(Eq. 11)}$$

$$LnK_{Cal.} = (-\ \mathit{delta}VK_{Cal.} + 0.5\ \mathit{kappa}K_{Cal.}\ P)\ P / RT_{°K} \quad \text{(Eq. 12)}$$

where $RT_{°K}$ is the products of the gas constant (83.145) and the Kelvin temperature, while P is pressure in bars. Then, the $IAP_{Cal.}$ is the product of the T- and S-corrected values and the exponential of Eq. 12:

$$IAP_{Cal.} (T, S, P) = IAP_{Cal.} (T, S)\ e^{LnK_{Cal.}} \quad \text{(Eq. 13)}$$

Aragonite:

$$\mathit{delta}VK_{Arag.} = \mathit{delta}VK_{Cal.} + 2.80 \quad \text{(Eq. 14)}$$

$$\mathit{kappa}K_{Arag.} = -\mathit{kappa}K_{Cal.} \quad \text{(Eq. 15)}$$

$$LnK_{Arag.} = (-\ \mathit{delta}VK_{Arag.} + 0.5\ \mathit{kappa}K_{Arag.}\ P)\ P / RT_{°K} \quad \text{(Eq. 16)}$$

where $RT_{°K}$ is the product of the gas constant ($R = 8.314\ m^3\ Pa / K\ mol$) and the Kelvin temperature $T_{°K}$), and P is the pressure in bar. The $IAP_{Arag.}$ is the product of the T- and S-corrected IAP values and the exponential of Eq. 16:

$$IAP_{Arag.} (T, S) = IAP_{Arag.} (T, S)\ e^{LnK_{Arag.}} \quad \text{(Eq. 17)}$$

For each mol % $MgCO_3$, we used the individual IAP_i based on the biogenic "clean" and biogenic "minimally prepared" experimental solubility curves (Suppl. Fig. S1) [Plummer & Mackenzie, 1974; Bischoff *et al.,* 1987]. These two curves differ in the way the experimental materials dissolved are prepared. There is not enough information on which curve best represents the solubility of Mg-calcite mineral phases, but several published studies support the use of the "minimally prepared" solubility curve [Tribble *et al.,* 1995; Andersson *et al.,* 2007]. Here, we provide results employing both solubility curves, but we focus on the "minimally prepared" results. The IAP_i was calculated individually for each mol % $MgCO_3$ from the following equations fitted to the "cleaned" and "minimally prepared" curves (Suppl. Fig. S1) at $T_{°C}$ = 25 °C and S = 35.00. Since empirical data only exist from 0 to 20 mol % $MgCO_3$ for the "cleaned" and "minimally prepared" curves, we fitted a curve in this range adjusting the r^2 to 0.99, and then a separate curve on samples above mol % $MgCO_3$ with a value of 20 % (Suppl. Fig. S1). Both equations are used in our calculations. For these equations we call mol % $MgCO_3$ the variable "X" for simplicity:

Biogenically cleaned

0–20mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\,(\text{cleaned})} = -8*10^{-6} X^4 + 0.0004 X^3 - 0.0072 X^2 + 0.0318 X + 8.3617 \qquad \text{(Eq. 18a)}$$

> 20 mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\,(\text{cleaned})} = -0.0205 X + 8.4978 \qquad \text{(Eq. 18b)}$$

Minimally prepared

0–20mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\,(\text{min. prep.})} = 2*10^{-7} X^4 + 0.0003 X^3 - 0.0106 X^2 + 0.0358 X + 8.4508 \qquad \text{(Eq. 19a)}$$

> 20 mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\,(\text{min. prep.})} = -0.0404 X + 8.1528 \qquad \text{(Eq. 19b)}$$

Because the "cleaned" and "minimally prepared" solubility curves were determined at $T_{°C}$ = 25 °C, S = 35.00, and P = 1 atm, we worked out a T and P correction for the IAP_i as a function of the mol % $MgCO_3$ (the salinity effect is minor as previously discussed). First, we corrected the IAP_i for the corresponding mol % $MgCO_3$ (using Eqs. 18 and 19) assuming a similar effect on the solubility by

T and P as for calcite. Then, we fitted a curve to the field T data obtained from the NEAR 3D analysis (Suppl. Fig. S5) to work out the $IAP_{Cal.}$ vs. temperature equation:

$$-\log IAP_{Cal.} = 0.0001\ T^2 + 0.0001\ T + 8.3576 \qquad \text{(Eq. 20)}$$

This equation was used to correct the original IAP_i from the mol % $MgCO_3$ (called variable "X") in Eqs. 18 and 19 for T and S. This was done by substituting the intercept of Eq. 20 (8.3576) by Eqs. 18 and 19:

Biogenically cleaned

0–20 mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\ \text{(cleaned)}}\ (T) = (0.0001\ T^2 + 0.0001\ T) - (-8*10^{-6}\ X^4 + 0.0004\ X^3 - 0.0072\ X^2 + 0.0318\ X + 8.3617) \qquad \text{(Eq. 21a)}$$

> 20 mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\ \text{(cleaned)}}\ (T) = (0.0001\ T^2 + 0.0001\ T) + (-0.0205\ X + 8.4978) \qquad \text{(Eq. 21b)}$$

Minimally prepared

0–20mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\ \text{(min. prep.)}}\ (T) = (0.0001\ T^2 + 0.0001\ T) - (2*10^{-7}\ X^4 + 0.0003\ X^3 - 0.0106\ X^2 + 0.0358\ X + 8.4508) \qquad \text{(Eq. 22a)}$$

> 20 mol % $MgCO_3$:

$$-\log IAP_{Mg\text{-}x\ \text{(min. prep.)}}\ (T) = (0.0001\ T^2 + 0.0001\ T) + (-0.0404\ X + 8.1528) \qquad \text{(Eq. 22b)}$$

The IAP_i was finally corrected for P assuming a similar behaviour to calcite by using the correction factor calculated in Eq. 12:

Biogenically cleaned

$$-\log IAP_{Mg\text{-}x\ \text{(cleaned)}}\ (T, P) = -\log IAP_{Mg\text{-}x\ \text{(cleaned)}}\ (T, S)\ e^{\mathrm{Ln}K_{Cal.}} \qquad \text{(Eq. 23)}$$

Minimally prepared

$$-\log IAP_{Mg\text{-}x\ \text{(min. prep.)}}\ (T, P) = -\log IAP_{Mg\text{-}x\ \text{(min. prep.)}}\ (T, S)\ e^{\mathrm{Ln}K_{Cal.}} \qquad \text{(Eq. 24)}$$

All Ω_i calculations were plotted against depth for various mol % $MgCO_3$ values using North Atlantic Ocean profiles taken from the GLODAP (13) dataset at latitude 25 ºN, 70 ºW at 26 discrete depths from 51 to 5600 m (Suppl. Fig. S3). They were also tested against latitude, using the same environmental conditions as for the organisms, but with fixed mol % $MgCO_3$ values. The depth and latitude plots show that our corrections for T and P worked correctly and are representative of vertical and horizontal oceanic profiles. This allows their use in future studies in which the mol % $MgCO_3$ is known until we have more experimental data on Mg-calcite solubilities at in situ T and P.

7.2 References

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Fig. S1. Solubility curves fitted to IAP_i data to calculate Ω_i as a function of the mol % $MgCO_3$ in the phase. Also included are the fitted curves to IAP_i and equations. Note that owing to the shape of the curves we extrapolated linearly after 20 mol % $MgCO_3$ using the last four data points. The box plot shows the range of mol % $MgCO_3$ from all the samples used in this study classified per taxa. See Supplementary Information for the full development of the equations.

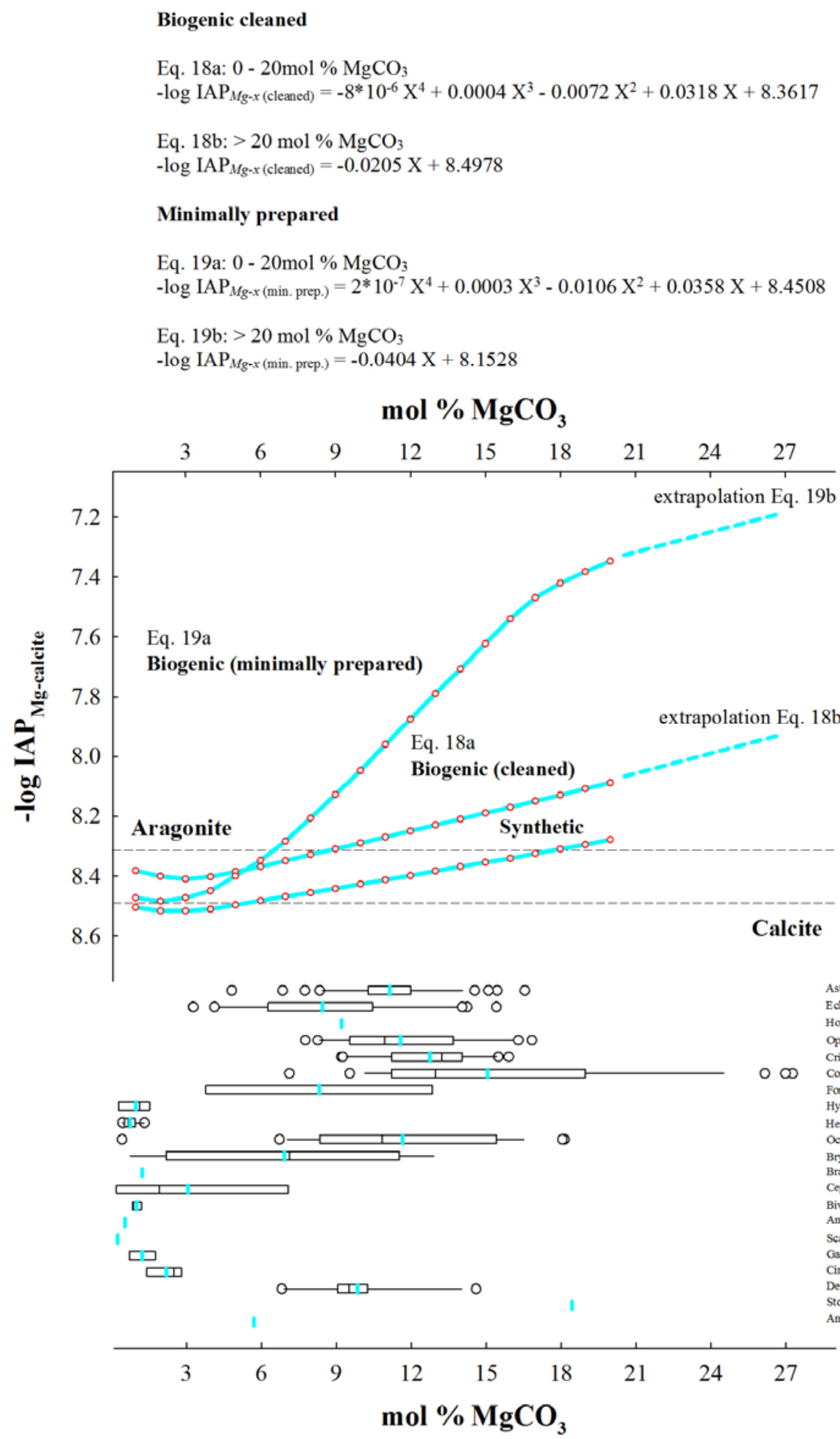

Fig. S2. Exploratory plots of environmental conditions. (a) Temperature versus latitude. (b) Salinity versus latitude. (c) $[CO_3^{2-}]$ versus latitude in present and future scenarios. (d) $[CO_3^{2-}]$ versus salinity.

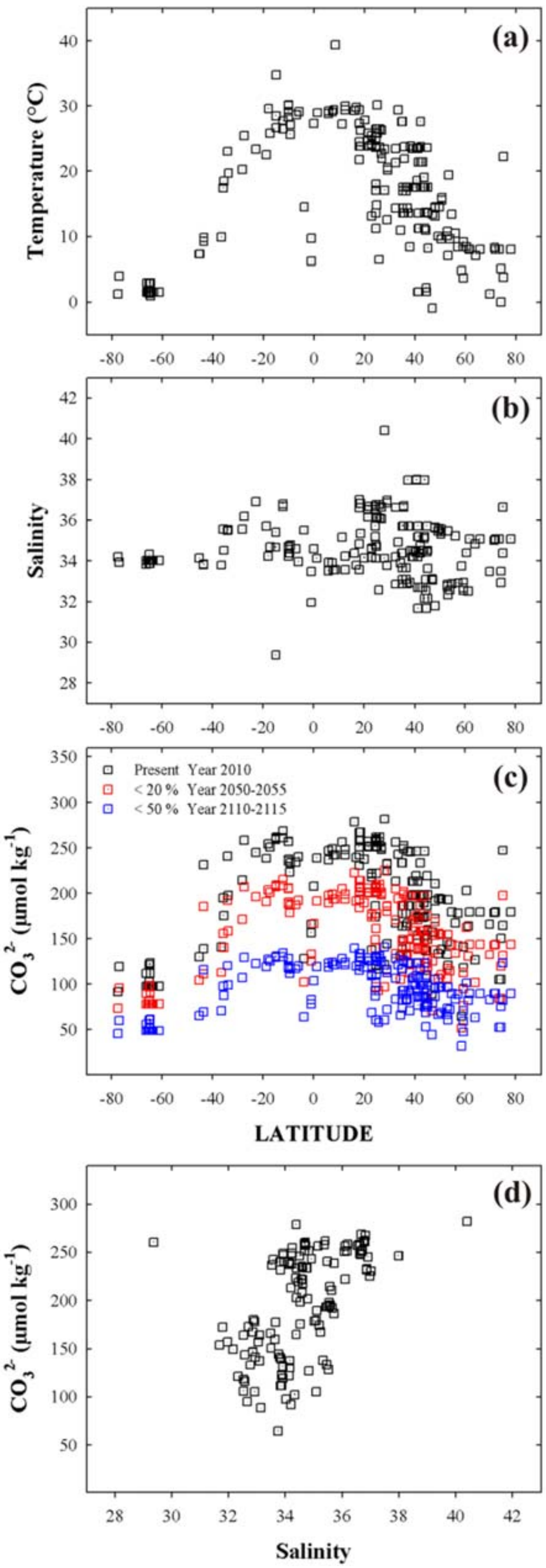

Fig. S3. Ω_i distribution with depth and latitude. (a) Salinity, temperature, and $[CO_3^{2-}]$ profiles obtained at 25 ºN, 70 ºW (26 depth-levels from 50 to 5600 m) from the GLODAP and WAVES dataset http://cdiac3.ornl.gov/waves/discrete/. (b) and (c) $\Omega_{Mg\text{-}x\ \text{(cleaned)}}$ and $\Omega_{Mg\text{-}x\ \text{(min. prep.)}}$ curves, respectively. All curves are calculated at 5, 8, 12, and 25 mol % $MgCO_3$. (d) $\Omega_{Mg\text{-}x\ \text{(cleaned)}}$ and (e) $\Omega_{Mg\text{-}x\ \text{(min. prep.)}}$ distributions with latitude. In these plots, the same environmental conditions used for the organisms were used with fixed mol % $MgCO_3$ values (5, 8, 12, and 25 mol % $MgCO_3$) to verify the latitudinal signal. Panels (d) and (e) are only meant to show the shape of the relationship. In panels (b) and (c) the box shows that for surface conditions $\Omega_{Arag.}$ is equivalent to $\Omega_{Mg\text{-}x\ \text{(cleaned)}}$ and $\Omega_{Mg\text{-}x\ \text{(min. prep.)}}$ of 12 and 8 % mol $MgCO_3$, respectively. This is what should be expected from the IAP_i.

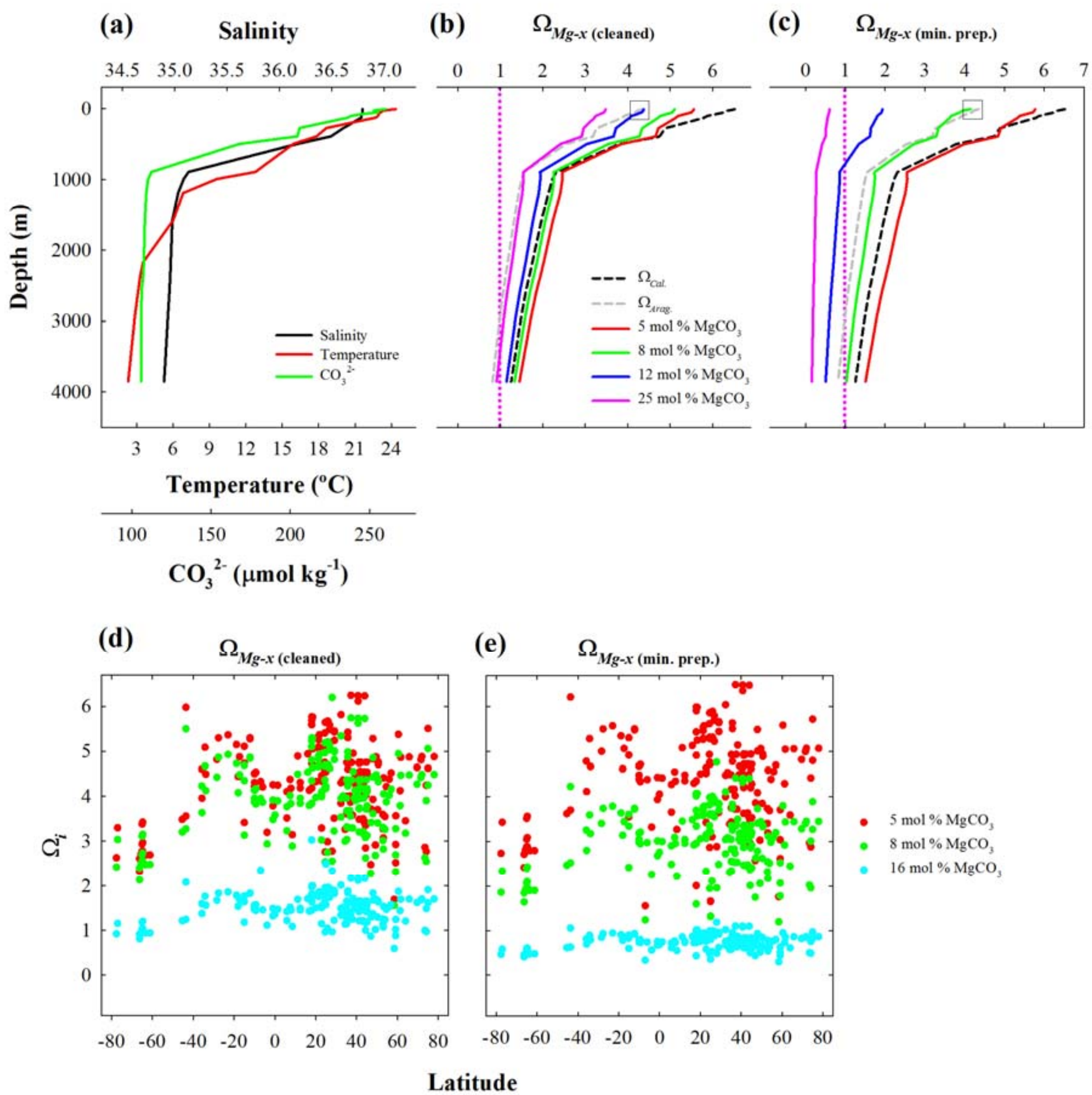

Fig. S4. Decline of [CO_3^{2-}] with time as simulated with the UVic Earth System Model (Keller *et al.,* 2012) forced with CO_2 emissions following the Representative Concentration Pathway (RCP) 8.5 scenario, which is a "business-as-usual," high-CO_2-emission scenario (Keller *et al.,* 2014). (a) Global mean (solid black), tropical (30ºS-30ºN; dashed blue) and extra-tropical (dashed red) [CO_3^{2-}] decline. (b), (d) Regional distribution of the year of emergence of a 20% and 50% reduction in surface [CO_3^{2-}], respectively. (c), (e) Regional distribution of the year of emergence of a 20% and 50% reduction in seafloor [CO_3^{2-}], respectively. Note the different time frames for surface and seafloor [CO_3^{2-}] changes. White areas mean that the bottom does not see the respective change before year 3000.

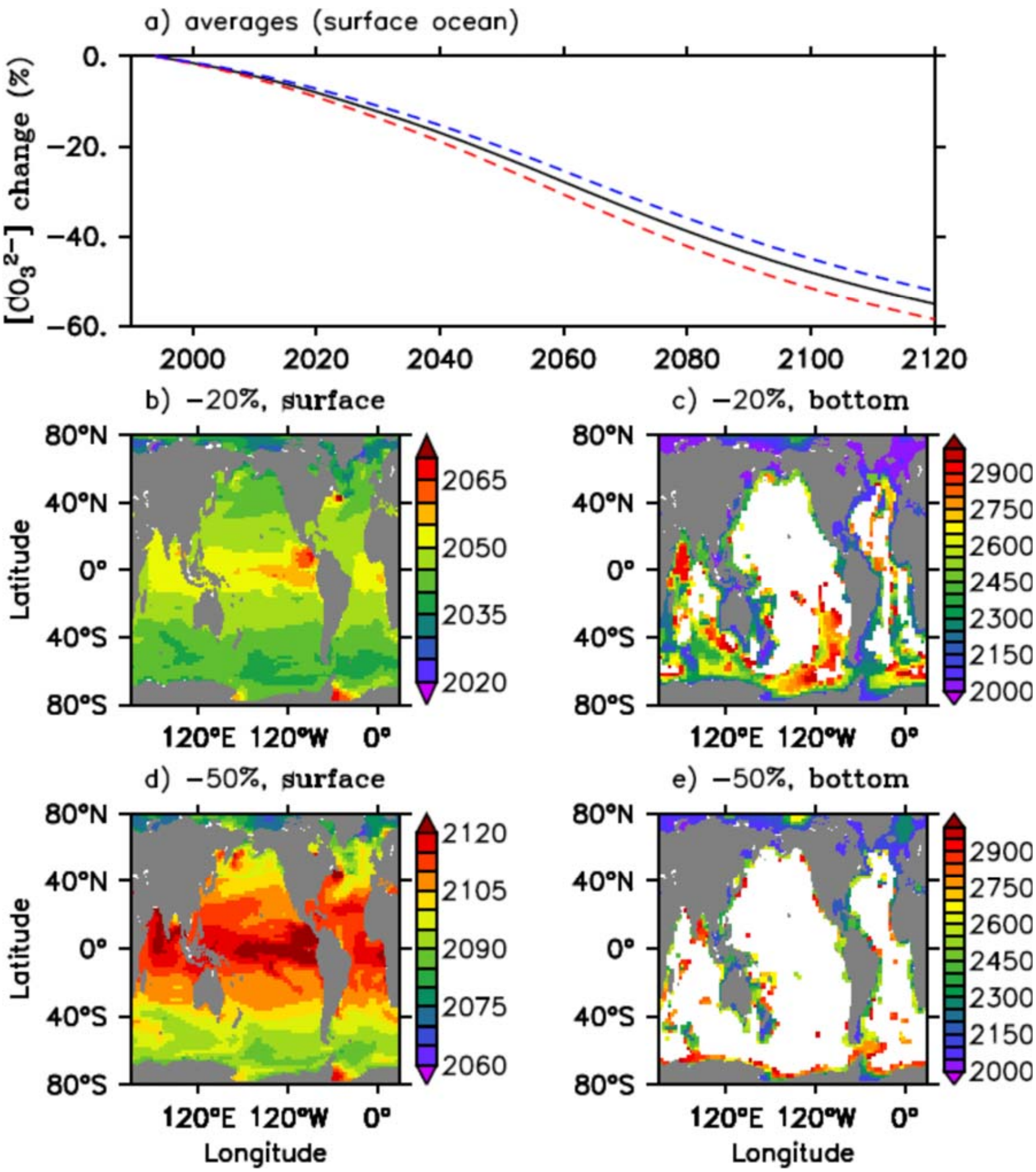

Fig. S5. Correction of the temperature (T) effect on the Mg-calcite IAP_i from the calcite data.

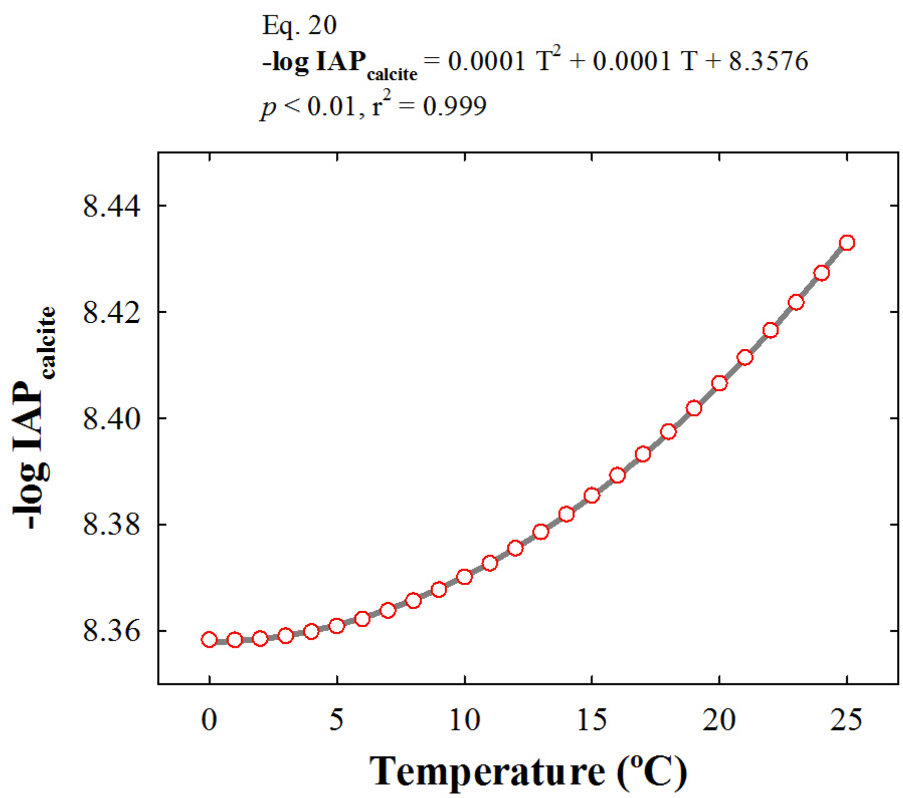

Table S1. Details of taxa used, skeletal mineralogy, and metadata.

Organisms				Field data			Mg-calcite - Analytics [a]			In situ conditions - NEAR 3D analysis [b]					
Taxa	Class	Species	*n*	Depth (m)	Lat.	Long.	$CaCO_3$ % dw	$MgCO_3$ % dw	Mg/Ca (mol/mol)	S	T (°C)	T (°K)	CO_3^{2-} (μmol kg^{-1}) [c] Present Year 2010	< 20 % Year 2050-2055	< 50 % Year 2110-2115
Echinodermata	Asteroidea	*Labidiaster annulatus*	9	175	-61.21	-56.01	90.120	9.870	0.130	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Macroptychaster accrescens*	3	180	-63.53	-62.75	90.170	9.830	0.129	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Paralophaster godfroyi*	1	180	-63.53	-62.75	90.410	9.590	0.126	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Paralophaster* sp.	3	180	-63.53	-62.75	90.720	9.280	0.121	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Perknaster* sp.	2	180	-63.53	-62.75	91.010	8.990	0.117	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Acodontaster hodgsoni*	3	160	-64.15	-62.74	90.150	9.850	0.130	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Kampylaster incurvatus*	4	160	-64.15	-62.74	90.720	9.280	0.121	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Odontaster penicillatus*	1	160	-64.15	-62.74	90.090	9.910	0.131	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Porania antarctica*	3	160	-64.15	-62.74	89.800	10.200	0.135	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Diplasterias brandti*	3	30	-64.77	-64.05	90.480	9.520	0.125	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Granaster nutrix*	5	30	-64.77	-64.05	91.710	8.290	0.107	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Neosmilaster georgianus*	3	30	-64.77	-64.05	90.630	9.370	0.123	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Odontaster meridionalis*	3	30	-64.77	-64.04	90.500	9.500	0.125	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Perknaster aurorae*	3	30	-64.78	-63.99	91.140	8.510	0.111	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Acodontaster conspicuus*	1	30	-65.07	-63.97	90.610	9.390	0.123	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Perknaster fuscus antracticus*	1	30	-65.07	-63.97	90.080	9.920	0.131	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Henricia* sp.	2	155	-65.67	-67.40	90.180	9.820	0.129	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Asteroidea	*Diplopteraster verrucosus*	2	900	-66.29	-66.60	89.630	8.120	0.108	34.03	1.54	274.69	97.85	78.28	48.93
Echinodermata	Echinoidea	*Diadema setosum*	3	0.5	-18.85	159.75	83.070	13.300	0.190	35.71	22.56	295.71	238.74	190.99	119.37
Echinodermata	Echinoidea	*Evechinus chloroticus*	3	5	-45.30	166.97	88.310	9.530	0.128	34.15	7.34	280.49	130.46	104.37	65.23
Echinodermata	Echinoidea	*Pseudechinus huttoni*	2	8	-45.41	167.10	94.910	4.000	0.050	34.15	7.34	280.49	130.46	104.37	65.23
Echinodermata	Echinoidea	*Pseudechinus huttoni*	3	8	-45.41	167.10	92.640	5.570	0.071	33.87	1.01	274.16	111.82	89.46	55.91
Echinodermata	Echinoidea	*Amphineustes similis*	2	685	-64.75	-65.47	96.300	3.700	0.046	33.87	1.01	274.16	111.82	89.46	55.91
Echinodermata	Echinoidea	*Amphineustes similis*	4	685	-64.75	-65.47	92.490	7.510	0.096	33.87	1.01	274.16	111.82	89.46	55.91
Echinodermata	Echinoidea	*Ctenocidaris perrieri*	3	685	-64.75	-65.47	96.180	3.810	0.047	33.87	1.01	274.16	111.82	89.46	55.91
Echinodermata	Echinoidea	*Ctenocidaris perrieri*	3	685	-64.75	-65.47	92.390	7.610	0.098	34.34	1.32	274.47	102.46	81.97	51.23
Echinodermata	Echinoidea	*Sterechinus neumayeri*	3	30	-65.07	-63.97	96.500	3.490	0.043	33.87	3.01	276.16	121.82	97.46	60.91
Echinodermata	Echinoidea	*Sterechinus neumayeri*	6	30	-65.07	-63.97	93.960	6.040	0.076	33.92	3.99	277.14	119.53	95.62	59.76
Echinodermata	Echinoidea	*Sterechinus neumayeri*	3	30	-65.07	-63.97	94.140	2.770	0.035	33.87	3.01	276.16	121.82	97.46	60.91
Echinodermata	Ophiuroidea	*Ophionotus victoriae*	3	30	-64.77	-64.05	90.800	9.200	0.120	36.86	20.16	293.31	232.04	185.63	116.02
Echinodermata	Ophiuroidea	*Ophiosparte gigas*	1	30	-64.77	-64.05	90.870	9.130	0.119	37.98	17.54	290.69	246.65	197.32	123.32
Echinodermata	Asteroidea	*Asterias linckii*	1	20	65.81	39.73	88.010	9.460	0.128	34.52	17.58	290.73	198.69	158.95	99.34

Echinodermata	Asteroidea	*Orthasterias tanneri*	1	30	61.68	3.31	86.410	10.690	0.147	35.09	8.07	281.22	179.42	143.54	89.71
Echinodermata	Asteroidea	*Ctenodiscus crispatus*	1	80	46.90	-59.10	88.480	8.780	0.118	33.13	-0.87	272.28	88.68	70.94	44.34
Echinodermata	Asteroidea	*Pisaster giganteus*	1	10	34.39	-119.68	n/a	16.85	n/a	34.7433	34.74	24.11	297.26	248.52	198.82
Echinodermata	Asteroidea	*Unidentified*	1	5	24.89	-80.99	n/a	10.41	n/a	35.2028	35.20	21.92	295.07	234.99	187.99
Echinodermata	Asteroidea	*Asterias vulgaris*	1	10	44.79	-66.92	91.060	7.790	0.102	33.83	9.25	282.40	231.81	185.45	115.90
Echinodermata	Asteroidea	*Asterias acervata borealis*	1	40	43.58	-65.17	86.390	9.600	0.132	35.09	8.07	281.22	179.42	143.54	89.71
Echinodermata	Asteroidea	*Asterias forbesi*	1	10	41.42	-70.80	88.190	8.240	0.111	35.20	11.27	284.42	174.45	139.56	87.23
Echinodermata	Asteroidea	*Odontaster hispidus*	1	40	41.30	-70.80	87.160	10.580	0.144	33.09	17.60	290.75	163.99	131.19	81.99
Echinodermata	Asteroidea	*Plutonaster agassizii*	1	10	41.30	-70.80	89.180	9.090	0.121	32.71	21.39	294.54	173.17	138.53	86.58
Echinodermata	Asteroidea	*Pontaster tenuispinus*	1	40	41.30	-70.80	89.340	8.860	0.118	34.52	17.58	290.73	198.69	158.95	99.34
Echinodermata	Asteroidea	*Leptasterias compta*	1	100	40.28	-69.85	86.570	10.270	0.141	34.52	18.51	291.66	175.82	140.66	87.91
Echinodermata	Asteroidea	*Benthopecten spinosus*	1	100	39.25	-68.13	86.420	9.880	0.136	35.72	13.61	286.76	186.56	149.25	93.28
Echinodermata	Asteroidea	*Astropecten articulatus*	1	200	35.71	-73.50	85.080	13.020	0.182	35.72	13.61	286.76	186.56	149.25	93.28
Echinodermata	Asteroidea	*Urasterias linckii*	1	200	35.71	-73.50	88.250	8.910	0.120	35.72	13.61	286.76	186.56	149.25	93.28
Echinodermata	Asteroidea	*Asterias tanneri*	1	200	35.71	-73.50	87.440	10.280	0.140	35.72	13.61	286.76	186.56	149.25	93.28
Echinodermata	Asteroidea	*Asterina miniata*	1	10	35.20	-121.30	88.060	11.240	0.152	35.72	13.61	286.76	186.56	149.25	93.28
Echinodermata	Asteroidea	*Astropecten americanus*	1	10	26.90	-82.80	87.930	10.110	0.136	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Asteroidea	*Asterina minuta*	1	15	18.04	-67.96	86.770	12.530	0.171	33.65	17.00	290.15	177.33	141.86	88.66
Echinodermata	Asteroidea	*Linckia guildingii*	1	30	18.04	-67.96	83.420	14.310	0.204	36.63	21.94	295.09	249.23	199.39	124.62
Echinodermata	Asteroidea	*Acanthaster planci*	1	25	5.86	-162.08	85.990	13.330	0.184	33.93	28.88	302.03	247.41	197.93	123.70
Echinodermata	Asteroidea	*Ctenodiscus procurator*	1	30	-35.70	-72.80	87.520	11.160	0.151	34.84	27.32	300.47	251.49	201.19	125.75
Echinodermata	Crinoidea	*Heliometra glacialis*	1	20	68.20	39.20	88.500	9.500	0.127	34.96	6.73	279.88	176.54	141.23	88.27
Echinodermata	Crinoidea	*Ptilocrinus pinnatus*	1	10	53.10	-130.00	88.480	7.910	0.106	32.33	7.14	280.29	121.11	96.89	60.56
Echinodermata	Crinoidea	*Florometra asperrima*	1	12	47.10	-124.20	89.450	9.440	0.125	33.05	13.40	286.55	157.09	125.67	78.55
Echinodermata	Crinoidea	*Bythocrinus robustus*	1	40	42.30	-70.77	87.160	10.090	0.137	32.71	21.39	294.54	173.17	138.53	86.58
Echinodermata	Crinoidea	*Psathyrometra fragilis*	1	20	35.07	139.70	87.770	9.250	0.125	34.38	27.65	300.80	233.89	187.11	116.94
Echinodermata	Crinoidea	*Pentametrocrinus japonicus*	1	20	34.90	138.50	87.340	10.150	0.138	32.71	21.39	294.54	173.17	138.53	86.58
Echinodermata	Crinoidea	*Crinometra concinna*	1	40	28.05	-96.02	87.960	11.690	0.158	35.54	19.72	292.87	198.10	158.48	99.05
Echinodermata	Crinoidea	*Isocrinus decorus*	1	50	21.40	-76.70	88.200	11.690	0.157	34.13	17.12	290.27	121.66	97.33	60.83
Echinodermata	Crinoidea	*Endoxocrinus parra*	1	60	21.40	-76.70	88.130	11.620	0.157	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Crinoidea	*Tropiometra picta*	1	30	21.40	-76.70	87.510	11.770	0.160	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Crinoidea	*Promachocrinus kerguelensis*	1	20	11.17	-60.68	91.550	7.860	0.102	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Crinoidea	*Capillaster multiradiata*	1	30	7.85	116.90	86.320	12.690	0.175	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Crinoidea	*Pachylometra patula*	1	30	7.85	116.90	85.810	12.200	0.169	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Crinoidea	*Catoptometra ophiura*	1	30	7.85	116.90	86.460	11.680	0.160	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Crinoidea	*Hypalocrinus naresianus*	1	30	7.85	116.90	89.660	10.160	0.135	36.17	25.83	298.98	251.71	201.37	125.86
Echinodermata	Crinoidea	*Parametra granulata*	1	30	7.85	116.90	87.860	11.080	0.150	36.17	25.83	298.98	251.71	201.37	125.86
Echinodermata	Crinoidea	*Craspedometra anceps*	1	30	7.85	116.90	86.930	12.340	0.169	36.17	25.83	298.98	251.71	201.37	125.86
Echinodermata	Crinoidea	*Zygometra microdiscus*	1	40	-5.99	134.10	85.480	13.370	0.186	36.91	23.39	296.54	245.45	196.36	122.73
Echinodermata	Crinoidea	*Tropiometra carinata*	1	15	-22.98	-43.20	83.130	13.740	0.196	35.16	27.24	300.39	256.78	205.43	128.39
Echinodermata	Crinoidea	*Pilometra mülleri*	1	20	-33.85	151.26	87.940	11.130	0.150	33.97	29.14	302.29	240.31	192.25	120.15

Echinodermata	Crinoidea	*Bathycrinus sp.*	1	3100	8.70	-55.80	n/a	8.56	n/a	34.73	1.63	274.78	82.32	65.86	41.16
Echinodermata	Crinoidea	*Bathycrinus sp.*	1	3100	8.70	-55.80	n/a	8.40	n/a	34.73	1.63	274.78	82.32	65.86	41.16
Echinodermata	Echinoidea	*Strongylocentrotus droebachiensis*	1	40	64.00	-38.00	93.130	5.990	0.076	34.83	7.12	280.27	127.16	101.73	63.58
Echinodermata	Echinoidea	*Echinarachnius parma*	1	32	59.20	-165.80	92.130	6.130	0.079	32.94	8.46	281.61	141.05	112.84	70.52
Echinodermata	Echinoidea	*Arbacia pustulosa*	1	15	40.76	14.35	90.080	7.720	0.102	33.85	9.80	282.95	139.04	111.23	69.52
Echinodermata	Echinoidea	*Echinus esculentus*	1	10	38.00	-1.02	89.640	8.840	0.117	34.38	27.14	300.29	223.35	178.68	111.67
Echinodermata	Echinoidea	*Paracentrotus lividus*	1	5	37.24	13.68	89.400	8.530	0.113	34.93	29.38	302.53	243.07	194.46	121.54
Echinodermata	Echinoidea	*Clypeaster testudinarius*	1	20	33.40	134.60	91.290	8.410	0.109	37.98	17.54	290.69	246.65	197.32	123.32
Echinodermata	Echinoidea	*Prionocidaris baculosa*	1	15	28.02	34.97	89.330	10.670	0.142	32.94	8.46	281.61	141.05	112.84	70.52
Echinodermata	Echinoidea	*Tetrocidaris affinis*	1	10	26.90	-82.80	89.350	9.300	0.124	36.08	26.28	299.43	251.16	200.93	125.58
Echinodermata	Echinoidea	*Mellita sexiesperforatus*	1	30	18.04	-67.96	85.020	11.910	0.166	31.96	9.77	282.92	156.89	125.51	78.45
Echinodermata	Echinoidea	*Tetrapygus niger*	1	20	-9.40	-78.50	90.520	6.270	0.082	36.19	25.42	298.57	258.80	207.04	129.40
Echinodermata	Echinoidea	*Heterocentrotus mammillatus*	1	20	-27.64	-144.33	86.420	12.260	0.168	40.40	23.37	296.52	282.07	225.66	141.04
Echinodermata	Echinoidea	*Lytechinus albus*	1	10	-43.60	-74.00	91.730	7.380	0.096	33.58	29.38	302.53	242.51	194.01	121.25
Echinodermata	Echinoidea	*Strongylocentrotus purpuratus*	1	10	34.80	-120.60	n/a	2.83	n/a	34.51	20.33	293.48	201.59	161.28	100.80
Echinodermata	Echinoidea	*Strongylocentrotus purpuratus*	1	10	37.80	-122.10	n/a	6.44	n/a	34.20	21.07	294.22	196.02	156.81	98.01
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	237	-60.62	-46.96	n/a	2.89	n/a	34.63	1.92	275.07	77.98	62.39	38.99
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	602	-74.66	-29.52	n/a	2.28	n/a	34.46	2.46	275.61	76.21	60.97	38.11
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	810	-75.54	-29.88	n/a	2.02	n/a	34.72	1.07	274.22	79.93	63.94	39.96
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	1480	-73.48	-22.66	n/a	1.93	n/a	34.73	2.00	275.15	81.23	64.99	40.62
Echinodermata	Echinoidea	*Eucidaris tribuloides*	1	5	24.65	-81.25	n/a	4.86	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Echinoidea	*unidentified Echinoid*	1	5	24.65	-81.25	n/a	4.83	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Echinoidea	*unidentified Echinoid*	1	5	24.65	-81.25	n/a	10.57	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Echinoidea	*Lytechinus variegatus*	1	5	24.79	-80.82	n/a	5.73	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Ophiuroidea	*Astrophyton* sp.	1	60	56.00	2.90	89.670	9.110	0.121	35.20	11.27	284.42	174.45	139.56	87.23
Echinodermata	Ophiuroidea	*Ophiopholis aculeata japonica*	1	10	53.91	-166.50	91.160	8.010	0.104	34.51	23.85	297.00	246.10	196.88	123.05
Echinodermata	Ophiuroidea	*Gorgonocephalus arcticus*	1	10	41.50	-70.30	86.600	9.530	0.131	32.57	9.62	282.77	143.70	114.96	71.85
Echinodermata	Ophiuroidea	*Ophioglypha sarsii*	1	100	39.54	-72.35	87.650	9.840	0.133	34.51	23.85	297.00	246.10	196.88	123.05
Echinodermata	Ophiuroidea	*Gorgonocephalus eucnemis*	1	50	38.30	139.00	88.440	8.390	0.113	35.24	10.50	283.65	167.52	134.02	83.76
Echinodermata	Ophiuroidea	*Ophionereis eurybrachiplax*	1	50	38.30	139.00	85.530	13.380	0.186	34.20	23.49	296.64	213.34	170.67	106.67
Echinodermata	Ophiuroidea	*Ophioglypha lütkeni*	1	200	35.20	-121.30	86.340	10.190	0.140	34.52	18.51	291.66	175.82	140.66	87.91
Echinodermata	Ophiuroidea	*Ophiothrix angulata*	1	200	21.40	-76.70	87.240	11.680	0.159	32.86	14.31	287.46	147.12	117.69	73.56
Echinodermata	Ophiuroidea	*Ophiocamax fasciculata*	1	100	21.40	-76.70	91.300	7.620	0.099	36.82	23.81	296.96	267.33	213.86	133.66
Echinodermata	Ophiuroidea	*Ophiocoma erinaceus*	1	20	20.10	-155.30	86.830	12.050	0.165	36.82	23.81	296.96	267.33	213.86	133.66
Echinodermata	Ophiuroidea	*Unidentified Ophiuroid*	1	5	25.01	-80.46	n/a	13.62	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Ophiuroidea	*Unidentified Ophiuroid*	1	5	24.65	-81.25	n/a	13.71	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Echinodermata	Ophiuroidea	*Ophioderma cinerum*	1	30	18.50	-66.60	85.090	14.080	0.196	36.82	23.81	296.96	267.33	213.86	133.66
Echinodermata	Ophiuroidea	*Ophiocoma aethiops*	1	25	18.04	-67.96	92.120	7.040	0.091	36.82	23.81	296.96	267.33	213.86	133.66
Echinodermata	Ophiuroidea	*Ophiomixa flaccida*	1	120	18.04	-67.96	81.020	14.560	0.213	34.16	27.86	301.01	237.55	190.04	118.78
Echinodermata	Ophiuroidea	*Ophiocoma pumila*	1	120	18.04	-67.96	84.440	12.970	0.182	36.53	24.79	297.94	257.40	205.92	128.70
Echinodermata	Ophiuroidea	*Ophiomusium lymani*	1	200	-1.00	-91.01	92.700	6.610	0.085	33.48	6.24	279.39	166.29	133.04	83.15

Echinodermata	Ophiuroidea	*Ophioglypha lymani*	1	30	-35.70	-72.80	89.500	8.240	0.109	36.53	24.79	297.94	257.40	205.92	128.70
Coralline algae	-	*Lithothamnium* sp.	1	10	78.00	20.00	84.830	8.670	0.121	35.09	8.07	281.22	179.42	143.54	89.71
Coralline algae	-	*Lithothamnium soriferum*	1	10	75.00	20.00	80.900	9.560	0.140	34.38	3.83	276.98	164.72	131.78	82.36
Coralline algae	-	*Lithothamnium glaciale*	1	10	75.00	20.00	83.100	13.190	0.188	36.66	22.27	295.42	247.54	198.03	123.77
Coralline algae	-	*Lithothamnium fornicatum*	1	10	72.00	20.00	88.610	10.090	0.135	35.09	8.07	281.22	179.42	143.54	89.71
Coralline algae	-	*Lithothamnium polymorphum*	1	10	57.00	12.00	74.220	9.100	0.146	32.92	8.45	281.60	178.18	142.54	89.09
Coralline algae	-	*Corallina squamata* - 29-Nov	1	5	50.60	-2.30	71.680	10.530	0.174	35.60	14.57	287.72	194.74	155.79	97.37
Coralline algae	-	*Corallina squamata* - 29-Jan	1	5	50.60	-2.30	72.420	9.650	0.158	35.64	14.40	287.55	192.09	153.67	96.04
Coralline algae	-	*Corallina squamata* - 26-Mar	1	5	50.60	-2.30	70.400	9.260	0.156	35.63	14.55	287.70	210.98	168.78	105.49
Coralline algae	-	*Corallina squamata* - 28-May	1	5	50.60	-2.30	71.050	8.670	0.145	31.79	13.16	286.31	172.11	137.69	86.06
Coralline algae	-	*Corallina squamata* - 01-Jul	1	5	50.60	-2.30	72.340	9.340	0.153	37.98	17.54	290.69	246.65	197.32	123.32
Coralline algae	-	*Corallina squamata* - 13-Aug	1	5	50.60	-2.30	71.290	9.790	0.163	32.86	14.31	287.46	167.12	133.69	83.56
Coralline algae	-	*Corallina squamata* - 12-Sep	1	5	50.60	-2.30	71.370	10.340	0.172	34.70	30.15	303.30	257.24	205.79	128.62
Coralline algae	-	*Corallina squamata* - 10-Oct	1	5	50.60	-2.30	72.460	10.190	0.167	34.70	30.15	303.30	258.24	206.59	129.12
Coralline algae	-	*Corallina officinalis*	1	5	49.60	-1.20	86.680	12.060	0.165	34.70	30.15	303.30	259.24	207.39	129.62
Coralline algae	-	*Lithothamnium calcareum*	1	10	48.08	-4.00	84.600	12.040	0.169	34.70	30.15	303.30	260.24	208.19	130.12
Coralline algae	-	*Lithophyllum incrustans*	1	10	48.00	-3.00	87.100	11.140	0.152	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Phymatolithon compactum*	1	10	48.00	-55.00	87.210	10.930	0.149	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Lithophyllum tortuosum*	1	20	44.00	9.00	77.580	9.830	0.150	34.67	28.50	301.65	259.46	207.56	129.73
Coralline algae	-	*Lithophyllum proboscideum*	1	15	37.00	-122.00	72.000	8.150	0.134	35.40	26.65	299.80	262.09	209.67	131.05
Coralline algae	-	*Goniolithon strictum* - old	1	30	25.00	-75.00	74.850	24.000	0.381	29.37	34.79	307.94	260.70	208.56	130.35
Coralline algae	-	*Goniolithon strictum* - old	1	30	25.00	-75.00	74.290	23.740	0.379	34.73	30.10	303.25	256.96	205.57	128.48
Coralline algae	-	*Goniolithon strictum* - young	1	30	25.00	-75.00	75.420	22.980	0.362	34.58	28.29	301.44	235.47	188.38	117.74
Coralline algae	-	*Lithophyllum pachydermum*	1	30	25.00	-75.00	83.060	15.430	0.221	34.23	29.17	302.32	238.10	190.48	119.05
Coralline algae	-	*Goniolithon acropectum*	1	20	18.00	-68.00	79.050	19.240	0.289	34.60	28.66	301.81	234.24	187.39	117.12
Coralline algae	-	*Amphiroa fragilissima*	1	10	18.00	-68.00	76.230	17.470	0.272	34.60	27.33	300.48	208.18	166.54	104.09
Coralline algae	-	*Lithothamnium nodosum*	1	5	0.00	-90.00	91.040	6.060	0.079	35.55	15.58	288.73	193.68	154.95	96.84
Coralline algae	-	*Lithophyllum oncodes*	1	30	-7.00	56.00	80.930	18.170	0.267	35.55	15.58	288.73	193.69	154.95	96.85
Coralline algae	-	*Goniolithon orthoblastum*	1	10	-10.00	145.00	86.220	13.660	0.188	35.55	15.58	288.73	193.69	154.95	96.85
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	17.373	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	17.548	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	14.843	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	15.890	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	18.595	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	19.641	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	19.729	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	n/a	19.031	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	n/a	14.582	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	n/a	16.763	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	n/a	16.239	n/a	36.61	24.55	297.70	258.94	207.15	129.47

Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	n/a	14.756	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	n/a	13.099	n/a	36.61	24.55	297.70	258.94	207.15	129.47
Coralline algae	-	*Lithothamnium erubescens*	1	10	-10.00	123.00	81.590	16.960	0.247	35.55	15.58	288.73	193.69	154.95	96.85
Coralline algae	-	*Archaeolithothamium episporum*	1	10	-10.00	80.00	83.470	13.090	0.186	35.55	15.58	288.73	193.69	154.95	96.85
Coralline algae	-	*Lithothamnium kaiseri*	1	10	-15.00	-172.00	72.800	16.150	0.263	35.55	15.58	288.73	193.69	154.95	96.85
Coralline algae	-	*Porolithon craspedium*	1	10	-15.00	-172.00	75.390	16.800	0.265	35.55	15.58	288.73	193.69	154.95	96.85
Coralline algae	-	*Porolithon oncodes*	1	10	-15.00	-172.00	78.200	13.750	0.209	35.55	15.58	288.73	193.69	154.95	96.85
Foraminifera	-	*Pulvinulina menardii* - pelagic	1	20	40.56	-66.15	77.020	3.670	0.057	34.46	23.63	296.78	219.31	175.45	109.66
Foraminifera	-	*Polytrema mineaccum* - benthic	1	100	25.00	-77.00	90.110	9.330	0.123	34.23	30.01	303.16	248.76	199.01	124.38
Foraminifera	-	*Orbitolites marginatis* - benthic	1	50	24.60	-81.96	89.010	10.550	0.141	34.38	29.29	302.44	278.83	223.07	139.42
Foraminifera	-	*Amphistegina lessonii* - pelagic	1	20	16.10	-22.95	92.850	4.900	0.063	34.68	25.82	298.97	251.31	201.04	125.65
Foraminifera	-	*Sphaeroidina dehiscens* - pelagic	1	20	12.40	121.60	84.380	1.790	0.025	36.10	26.49	299.64	256.56	205.25	128.28
Foraminifera	-	*Orbitolites complanata* - benthic	1	30	-17.30	177.47	86.460	12.520	0.172	36.10	26.49	299.64	256.56	205.25	128.28
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	n/a	13.099	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	n/a	11.528	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	n/a	11.877	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	n/a	12.575	n/a	36.72	23.73	296.88	252.33	201.86	126.16
Foraminifera	-	*Globigerinoides ruber*	1	5	11.84	-86.68	n/a	0.353	n/a	35.95	27.83	300.98	270.53	216.42	135.27
Foraminifera	-	*Globigerinoides ruber*	1	5	11.95	-86.68	n/a	0.441	n/a	35.95	27.83	300.98	270.53	216.42	135.27
Foraminifera	-	*Globigerinoides sacculifer*	1	5	11.95	-86.68	n/a	0.275	n/a	35.95	27.83	300.98	270.53	216.42	135.27
Foraminifera	-	*Globorotalia menardii*	1	5	25.03	-77.83	n/a	0.318	n/a	36.52	28.76	301.91	256.08	204.87	128.04
Foraminifera	-	*Hastigeria pelagica*	1	5	11.95	-86.68	n/a	0.423	n/a	35.95	27.83	300.98	270.53	216.42	135.27
Foraminifera	-	*Orbulina universa*	1	5	11.95	-86.68	n/a	0.493	n/a	35.95	27.83	300.98	270.53	216.42	135.27
Hydrocorallia	-	*Millepora alcicornis*	1	10	24.60	-81.96	98.220	0.950	0.011	36.17	25.83	298.98	251.71	201.37	125.86
Hydrocorallia	-	*Distichopora nitida*	1	20	7.40	151.50	98.220	0.240	0.003	36.81	26.46	299.61	261.14	208.91	130.57
Hydrocorallia	-	*Millepora braziliensis*	1	30	-12.20	-36.80	96.770	1.280	0.016	33.91	29.09	302.24	249.15	199.32	124.57
Hexacorallia	-	*Madracis decactis*	1	20	32.40	-64.90	99.060	0.760	0.009	36.10	26.49	299.64	256.56	205.25	128.28
Hexacorallia	-	*Siderastrea radians*	1	20	32.40	-64.90	99.270	0.480	0.006	36.10	26.49	299.64	256.56	205.25	128.28
Hexacorallia	-	*Flabellum alabastrum*	1	10	26.00	-77.20	99.420	0.370	0.004	36.10	26.49	299.64	256.56	205.25	128.28
Hexacorallia	-	*Acropora cervicornis*	1	15	26.00	-77.20	99.490	0.450	0.005	36.10	26.49	299.64	256.56	205.25	128.28
Hexacorallia	-	*Favia fragum*	1	20	24.60	-81.96	99.200	0.390	0.005	36.10	26.49	299.64	256.56	205.25	128.28
Hexacorallia	-	*Dasmosmilia lymani*	1	10	24.60	-81.96	98.710	0.630	0.008	36.63	21.35	294.50	256.94	205.55	128.47
Hexacorallia	-	*Balanophyllia floridana*	1	10	24.54	-81.80	98.050	1.110	0.013	35.36	26.32	299.47	257.85	206.28	128.93
Hexacorallia	-	*Paracyathus defilipii*	1	10	24.54	-81.80	98.320	0.870	0.011	36.77	23.72	296.87	262.37	209.90	131.19
Hexacorallia	-	*Porites lutea*	1	2	24.55	124.33	n/a	4.070	n/a	35.36	28.13	301.28	246.82	197.46	123.41
Hexacorallia	-	*Porites sp.*	1	2	-18.28	147.38	n/a	3.302	n/a	34.68	25.82	298.97	251.31	201.04	125.65
Hexacorallia	-	*Deltocyathus italicus*	1	20	18.50	-63.51	98.980	0.540	0.006	36.63	21.35	294.50	256.94	205.55	128.47
Hexacorallia	-	*Desmophyllum ingens*	1	15	-36.55	-73.00	99.210	0.590	0.007	33.80	9.92	273.15	141.30	113.04	70.65

Octocorallia	-	*Gorgonia* sp.	1	30	54.60	154.40	88.830	9.290	0.124	33.58	29.38	302.53	242.51	194.01	121.25
Octocorallia	-	*Alcyonium carneum*	1	50	45.18	-55.85	84.500	6.660	0.094	34.13	29.00	302.15	239.41	191.52	119.70
Octocorallia	-	*Paramuricea borealis*	1	50	45.18	-55.85	85.110	8.030	0.112	34.75	23.78	296.93	233.86	187.09	116.93
Octocorallia	-	*Alcyonium carneum*	1	50	45.18	-55.85	-	6.660		32.54	2.23	275.38	106.34	85.07	53.17
Octocorallia	-	*Pennatula aculeata*	1	50	44.45	-58.51	85.620	7.710	0.107	34.25	29.62	302.77	254.57	203.66	127.29
Octocorallia	-	*Paragorgia arborea*	1	50	44.36	-63.75	88.040	9.050	0.122	36.77	23.72	296.87	262.37	209.90	131.19
Octocorallia	-	*Paragorgia arborea*	1	50	43.00	-62.00	-	9.050		32.88	13.39	286.54	179.79	143.83	89.89
Octocorallia	-	*Corallium elatior*	1	40	42.25	130.91	86.570	11.560	0.159	33.64	8.23	281.38	159.71	127.77	79.86
Octocorallia	-	*Primnoa resedaeformis*	1	30	42.25	130.91	-	9.290		35.56	20.25	293.40	214.53	171.63	107.27
Octocorallia	-	*Primnoa reseda*	1	40	42.25	-63.25	-	6.180		35.48	23.06	296.21	240.96	192.77	120.48
Octocorallia	-	*Rhipidogorgia flabellum*	1	20	32.40	-64.90	83.380	12.640	0.180	35.48	23.06	296.21	240.96	192.77	120.48
Octocorallia	-	*Pleurocorallium johnsoni*	1	30	25.75	-20.20	93.870	6.030	0.076	35.48	23.06	296.21	240.96	192.77	120.48
Octocorallia	-	*Gorgonia acerosa*	1	50	24.60	-81.96	85.760	13.390	0.185	35.48	23.06	296.21	240.96	192.77	120.48
Octocorallia	-	*Leptogorgia pulchra*	1	80	24.60	-108.25	-	13.710		36.68	27.77	300.92	269.08	215.27	134.54
Octocorallia	-	*Xiphigorgia anceps*	1	20	24.47	-81.55	80.960	13.040	0.191	34.61	24.17	297.32	221.42	177.13	110.71
Octocorallia	-	*Eunicella singularis*	1	20	42.58	8.75	n/a	1.70	n/a	34.97	16.74	289.89	147.18	117.75	73.59
Octocorallia	-	*Eunicella cavolini*	1	20	42.58	8.75	n/a	2.00	n/a	34.97	16.74	289.89	147.18	117.75	73.59
Octocorallia	-	*Paramuricea clavata*	1	20	42.58	8.75	n/a	2.00	n/a	34.97	16.74	289.89	147.18	117.75	73.59
Octocorallia	-	*Corallium rubrum*	1	60	42.41	8.75	n/a	2.90	n/a	34.97	16.74	289.89	147.18	117.75	73.59
Octocorallia	-	*E. Barbadensis*	1	10	11.32	-60.7	n/a	4.99	n/a	33.81	29.52	302.67	216.37	173.10	108.19
Octocorallia	-	*Lepidisis spp.*	1	3945	-45.37	144.57	n/a	7.60	n/a	34.71	1.00	274.15	81.86	65.49	40.93
Octocorallia	-	*Tubipora musica*	1	5	14.21	122.06	n/a	13.45	n/a	34.63	27.22	300.37	265.60	212.48	132.80
Octocorallia	-	*Tubipora musica*	1	5	14.21	122.06	n/a	11.96	n/a	34.63	27.22	300.37	265.60	212.48	132.80
Octocorallia	-	*Tubipora musica*	1	5	14.21	122.06	n/a	11.18	n/a	34.63	27.22	300.37	265.60	212.48	132.80
Octocorallia	-	*Plexaurella grisea*	1	10	11.32	-60.59	n/a	15.63	n/a	34.01	29.57	302.72	229.15	183.32	114.58
Octocorallia	-	*Ellisella barbadensis*	1	10	11.32	-60.59	n/a	12.58	n/a	34.01	29.57	302.72	229.15	183.32	114.58
Octocorallia	-	*Muricea echinata*	1	10	22.86	-106.10	83.790	12.280	0.174	32.17	13.67	286.82	149.26	119.41	74.63
Octocorallia	-	*Leptogorgia rigida*	1	150	22.86	-109.79	-	14.130		33.09	10.98	284.13	137.16	109.73	68.58
Octocorallia	-	*Heliopora cerulea*	1	20	12.40	121.60	98.930	0.350	0.004	36.53	24.69	297.84	257.40	205.92	128.70
Octocorallia	-	*Tubipora purpurea*	1	10	1.33	103.83	84.610	12.230	0.172	34.20	23.49	296.64	213.34	170.67	106.67
Octocorallia	-	*Phyllogorgia quercifolia*	1	10	-3.83	-32.41	-	15.730		32.57	6.50	279.65	116.43	93.14	58.22
Octocorallia	-	*Ctenocella pectinata*	1	20	-10.00	142.20	-	15.650		34.38	27.65	300.80	233.89	187.11	116.94
Octocorallia	-	*Muricea humilis*	1	30	-12.20	-36.80	84.470	12.640	0.178	34.52	17.58	290.73	198.69	158.95	99.34
Octocorallia	-	*Gorgonia subfruticosa*	1	45	-18.00	-178.00	79.840	13.430	0.200	34.52	17.58	290.73	198.69	158.95	99.34
Octocorallia	-	*Plexaurella grandiflora*	1	20	-28.40	155.67	85.610	13.790	0.191	34.52	17.58	290.73	198.69	158.95	99.34
Octocorallia	-	*Eunicella papillose*	1	30	-34.21	18.35	62.050	5.720	0.109	34.13	17.12	290.27	121.66	97.33	60.83
Octocorallia	-	*Eunicella alba*	1	30	-34.22	18.48	68.700	7.050	0.122	34.17	13.17	286.32	137.43	109.95	68.72
Octocorallia	-	*Eunicella tricoronata*	1	30	-34.22	18.48	70.750	7.310	0.123	34.70	30.15	303.30	257.24	205.79	128.62
Octocorallia	-	*Lophogorgia flamea*	1	30	-34.22	18.48	75.510	7.990	0.126	35.51	14.55	287.70	128.14	102.51	64.07

Bryozoa	-	*Flustra membranacea*	1	50	59.17	-151.60	87.920	6.940	0.094	31.68	1.60	274.75	153.84	123.07	76.92
Bryozoa	-	*Cellepora incrassata*	1	50	44.69	-62.69	91.770	6.070	0.079	35.56	20.25	293.40	214.53	171.63	107.27
Bryozoa	-	*Schizoporella unicornis*	1	10	41.35	-70.79	95.970	0.630	0.008	31.68	1.60	274.75	153.84	123.07	76.92
Bryozoa	-	*Bugula turrita*	1	40	41.23	-70.07	64.510	10.190	0.188	32.67	3.72	276.87	94.96	75.97	47.48
Bryozoa	-	*Lepralia sp.*	1	20	40.80	14.20	90.820	5.020	0.066	37.99	18.54	291.69	246.65	197.32	123.32
Bryozoa	-	*Amathia spiralis*	1	20	35.22	-75.60	90.430	9.570	0.126	35.72	13.61	286.76	186.56	149.25	93.28
Bryozoa	-	*Holoporella albirostris*	1	20	24.47	-81.55	95.280	2.590	0.032	35.72	13.61	286.76	186.56	149.25	93.28
Bryozoa	-	*Bugula neritina*	1	20	24.47	-81.55	63.290	11.080	0.208	31.68	1.60	274.75	153.84	123.07	76.92
Bryozoa	-	*Microporella grisea*	1	20	-28.40	155.67	96.900	1.110	0.014	35.72	13.61	286.76	186.56	149.25	93.28
Bryozoa	-	*Adeonellopsis sp.*	1	12	-45.3	166.91	n/a	8.793	n/a	35.32	16.39	289.54	200.53	160.43	100.27
Bryozoa	-	*Bugula neritina*	1	5	26.71	-79.99	n/a	8.327	n/a	35.27	26.39	299.54	243.25	194.60	121.62
Bryozoa	-	*Bugula neritina*	1	5	26.88	-79.99	n/a	10.045	n/a	35.27	26.39	299.54	243.25	194.60	121.62
Brachiopoda	-	*Terebratulina septentrionalis*	1	30	44.87	-66.91	96.780	1.370	0.017	34.46	23.63	296.78	219.31	175.45	109.66
Brachiopoda	-	*Laqueus californicus*	1	80	24.60	-108.25	98.300	0.680	0.008	34.79	18.07	291.22	201.94	161.55	100.97
Brachiopoda	-	*Krassina rubra*	1	5	-34.25	18.35	n/a	0.64119340	n/a	35.08	14.17	287.32	163.63	147.26	130.90
Brachiopoda	-	*Megerlea truncata*	1	5	37.28	13.07	n/a	2.39466108	n/a	35.99	25.80	298.95	214.87	193.39	171.90
Brachiopoda	-	*Notosaris sp.*	1	5	-42.94	168.69	n/a	2.08933089	n/a	35.09	18.21	291.36	203.81	183.43	163.05
Brachiopoda	-	*Terebratella cruenta*	1	5	-42.84	168.69	n/a	0.49289016	n/a	35.09	18.21	291.36	203.81	183.43	163.05
Brachiopoda	-	*Stethothyris sp.*	1	5	-64.03	-61.82	n/a	0.44054785	n/a	33.84	1.80	274.95	108.92	98.02	87.13
Brachiopoda	-	*Thecidellina sp.*	1	5	12.31	-68.97	n/a	7.62016924	n/a	36.44	25.29	298.44	213.74	192.37	170.99
Brachiopoda	-	*Thecidellina sp.*	1	5	12.21	-68.97	n/a	8.01273663	n/a	36.44	25.29	298.44	213.74	192.37	170.99
Mollusca	Polyplacophora	*Mopalia muscosa*	1	120	34.39	-119.70	98.370	0.450	0.005	33.58	39.38	312.53	242.51	194.01	121.25
Mollusca	Bivalvia	*Astarte borealis*	1	50	74.16	54.40	98.700	0.620	0.007	35.56	17.46	290.61	195.19	156.15	97.60
Mollusca	Bivalvia	*Tellina calcarea*	1	40	74.16	54.33	98.840	0.710	0.009	33.52	29.26	302.41	237.13	189.71	118.57
Mollusca	Bivalvia	*Pecten groenlandicus*	1	20	73.50	68.83	90.000	0.800	0.011	36.66	22.69	295.84	248.58	198.86	124.29
Mollusca	Bivalvia	*Pecten islandicus*	1	40	71.50	47.00	97.600	1.280	0.016	34.57	25.51	298.66	222.38	177.91	111.19
Mollusca	Bivalvia	*Pecten dislocatus*	1	10	26.81	-82.29	98.000	1.000	0.012	35.02	8.36	281.51	178.97	143.18	89.49
Mollusca	Bivalvia	*Pecten ventricosus*	1	10	22.86	-106.10	98.980	0.730	0.009	35.09	8.07	281.22	105.33	84.26	52.67
Mollusca	Bivalvia	*Placuna orbicularis*	1	10	16.83	120.26	99.220	0.700	0.008	32.93	5.10	278.25	105.33	84.26	52.67
Mollusca	Cephalopoda	*Nautilus pompilius*	1	100	8.53	123.03	99.500	0.160	0.002	33.80	29.76	302.91	239.93	191.94	119.97
Mollusca	Cephalopoda	*Sepia officinalis*	1	10	5.84	118.27	98.320	1.620	0.020	33.50	0.00	273.15	150.49	120.39	75.24
Mollusca	Cephalopoda	*Argonauta argo*	1	50	-35.82	175.39	93.760	6.020	0.076	33.91	10.93	284.08	131.88	105.50	65.94
Mollusca	Gastropoda	*Neptunea despecta*	1	20	69.63	57.35	98.520	1.170	0.014	34.40	8.45	281.60	203.08	162.46	101.54
Mollusca	Gastropoda	*Natica clausa*	1	20	60.50	-46.91	98.540	0.840	0.010	34.20	23.49	296.64	213.34	170.67	106.67
Mollusca	Gastropoda	*Tachyrhynchus erosa*	1	30	52.90	158.76	97.000	1.020	0.012	34.20	23.49	296.64	213.34	170.67	106.67
Mollusca	Gastropoda	*Nassa tegula*	1	20	36.62	-121.91	99.220	0.370	0.004	36.69	23.84	296.99	251.09	200.87	125.54
Mollusca	Gastropoda	*Odontocymbiola magellanica*	1	15	-42.71	-65.02	n/a	13.45	n/a	34.36	8.45	281.60	147.34	117.87	73.67
Mollusca	Gastropoda	*Nassa isculpta*	1	50	32.34	-118.43	97.080	1.780	0.022	34.61	24.08	297.23	217.84	174.27	108.92
Mollusca	Scaphopoda	*Dentalium solidum*	1	30	41.23	-70.07	99.130	0.200	0.002	32.85	10.77	283.92	146.62	117.30	73.31

Crustacea	Cirripedia	*Scalpellum regium*	1	5	52.92	-132.29	97.020	2.230	0.027	34.20	23.49	296.64	213.34	170.67	106.67
Crustacea	Cirripedia	*Balanus hameri*	1	20	41.23	-70.07	99.070	0.750	0.009	33.65	17.00	290.15	177.33	141.86	88.66
Crustacea	Cirripedia	*Balanus amphitrite*	1	5	38.92	-74.91	95.630	1.630	0.020	32.86	14.31	287.46	167.12	133.69	83.56
Crustacea	Cirripedia	*Lepas anatifera*	1	10	24.47	-81.55	97.270	2.490	0.030	32.76	10.07	283.22	133.16	106.53	66.58
Crustacea	Cirripedia	*Mitella polymerus*	1	10	22.86	-106.10	97.470	2.110	0.026	33.49	1.30	274.45	165.83	132.66	82.92
Crustacea	Amphipoda	*Tryphosa pinguis*	1	30	41.52	-70.67	74.640	4.840	0.077	35.20	11.27	284.42	174.45	139.56	87.23
Crustacea	Isopoda	*Pentidotea wosnesenkii*	1	2	48.75	-125.23	n/a	5.841	n/a	35.26	13.97	287.12	163.77	131.02	81.89
Crustacea	Isopoda	*Sphaeroma serratum*	1	2	45.18	13.68	n/a	4.759	n/a	35.45	12.35	285.50	144.06	115.25	72.03
Crustacea	Isopoda	*Gnovimosphaeroma oregonensis*	1	2	48.75	-125.23	n/a	4.689	n/a	35.26	13.97	287.12	163.77	131.02	81.89
Crustacea	Decapoda	*Crago dalli*	1	40	59.17	-151.60	54.830	10.050	0.218	33.75	4.84	277.99	64.67	51.74	32.34
Crustacea	Decapoda	*Pagurus rathbuni*	1	210	58.46	-175.22	78.030	5.800	0.088	36.69	23.84	296.99	251.09	200.87	125.54
Crustacea	Decapoda	*Homarus americanus* - small	1	30	43.84	-69.64	78.980	7.740	0.116	32.54	9.23	282.38	118.47	94.78	59.24
Crustacea	Decapoda	*Homarus americanus* - medium	1	30	43.84	-69.64	70.580	8.120	0.137	33.09	17.60	290.75	163.99	131.19	81.99
Crustacea	Decapoda	*Homarus americanus* - large	1	30	43.84	-69.64	65.140	8.770	0.160	34.77	25.68	298.83	233.55	186.84	116.77
Crustacea	Decapoda	*Homarus americanus*	1	50	41.35	-70.79	79.500	8.020	0.120	35.20	11.27	284.42	174.45	139.56	87.23
Crustacea	Decapoda	*Libinia emarginata*	1	20	41.35	-70.79	76.440	8.650	0.134	35.72	13.61	286.76	186.56	149.25	93.28
Crustacea	Decapoda	*Munida iris*	1	20	37.62	-76.26	82.640	8.710	0.125	32.17	13.67	286.82	149.26	119.41	74.63
Crustacea	Decapoda	*Pandalus platyceros*	1	50	36.62	-121.91	60.940	8.090	0.158	35.20	11.27	284.42	174.45	139.56	87.23
Crustacea	Decapoda	*Palinurus argus*	1	60	21.84	-71.33	76.870	12.580	0.194	35.20	11.27	284.42	174.45	139.56	87.23
Crustacea	Decapoda	*Grapsus grapsus*	1	60	-9.36	46.40	72.770	6.180	0.101	35.20	11.27	284.42	174.45	139.56	87.23
Crustacea	Stomatopoda	*Chloridella empusa*	1	20	24.47	-81.55	28.560	15.990	0.665	35.20	11.27	284.42	174.45	139.56	87.23

[a] Literature data were measured via X-Ray difraction (see original ciation in Table S3 for methods) and the new data via inducted coupled plasma spectroscopy (ICP) (see text for the different procedures).

[b] See text for NEAR 3D analysis procedure to recover in situ field data.

[c] Scenarios of future $[CO_3^{2-}]$ taken assuming a 20 and 50 % reduction in the ion concentration with the other variables remaining constant.

Table S2. Details of data used in Ω_i calculations. Included are activity coefficients [$\gamma_T(i)$] used, calculated from in situ temperature.

Organisms			Field data				**Activity coefficients - $\gamma_T(i)$** (T-corrected) [b]		
Taxa	Class	Species	Depth (m)	Lat.	Long.	mol % $MgCO_3$	CO_3^{2-}	Mg^{2+}	Ca^{2+}
Echinodermata	Asteroidea	*Labidiaster annulatus*	175	-61.21	-56.01	11.506	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Macroptychaster accrescens*	180	-63.53	-62.75	11.460	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Paralophaster godfroyi*	180	-63.53	-62.75	11.185	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Paralophaster* sp.	180	-63.53	-62.75	10.830	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Perknaster* sp.	180	-63.53	-62.75	10.497	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Acodontaster hodgsoni*	160	-64.15	-62.74	11.483	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Kampylaster incurvatus*	160	-64.15	-62.74	10.830	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Odontaster penicillatus*	160	-64.15	-62.74	11.552	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Porania antarctica*	160	-64.15	-62.74	11.883	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Diplasterias brandti*	30	-64.77	-64.05	11.105	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Granaster nutrix*	30	-64.77	-64.05	9.692	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Neosmilaster georgianus*	30	-64.77	-64.05	10.933	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Odontaster meridionalis*	30	-64.77	-64.04	11.082	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Perknaster aurorae*	30	-64.78	-63.99	9.945	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Acodontaster conspicuus*	30	-65.07	-63.97	10.956	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Perknaster fuscus antracticus*	30	-65.07	-63.97	11.563	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Henricia* sp.	155	-65.67	-67.40	11.449	0.0514	0.2211	0.2068
Echinodermata	Asteroidea	*Diplopteraster verrucosus*	900	-66.29	-66.60	9.496	0.0514	0.2211	0.2068
Echinodermata	Echinoidea	*Diadema setosum*	0.5	-18.85	159.75	14.036	0.0451	0.2043	0.1984
Echinodermata	Echinoidea	*Evechinus chloroticus*	5	-45.30	166.97	4.714	0.0497	0.2164	0.2045
Echinodermata	Echinoidea	*Pseudechinus huttoni*	8	-45.41	167.10	6.545	0.0497	0.2164	0.2045
Echinodermata	Echinoidea	*Pseudechinus huttoni*	8	-45.41	167.10	4.363	0.0516	0.2215	0.2070
Echinodermata	Echinoidea	*Amphineustes similis*	685	-64.75	-65.47	8.793	0.0516	0.2215	0.2070
Echinodermata	Echinoidea	*Amphineustes similis*	685	-64.75	-65.47	4.492	0.0516	0.2215	0.2070
Echinodermata	Echinoidea	*Ctenocidaris perrieri*	685	-64.75	-65.47	8.908	0.0516	0.2215	0.2070
Echinodermata	Echinoidea	*Ctenocidaris perrieri*	685	-64.75	-65.47	4.117	0.0515	0.2212	0.2069
Echinodermata	Echinoidea	*Sterechinus neumayeri*	30	-65.07	-63.97	7.091	0.0510	0.2199	0.2062
Echinodermata	Echinoidea	*Sterechinus neumayeri*	30	-65.07	-63.97	5.333	0.0507	0.2191	0.2058
Echinodermata	Echinoidea	*Sterechinus neumayeri*	30	-65.07	-63.97	3.272	0.0510	0.2199	0.2062
Echinodermata	Ophiuroidea	*Ophionotus victoriae*	30	-64.77	-64.05	8.562	0.0459	0.2062	0.1993
Echinodermata	Ophiuroidea	*Ophiosparte gigas*	30	-64.77	-64.05	9.081	0.0466	0.2083	0.2004
Echinodermata	Asteroidea	*Asterias linckii*	20	65.81	39.73	11.197	0.0466	0.2082	0.2004

Echinodermata	Asteroidea	*Orthasterias tanneri*	30	61.68	3.31	11.036	0.0495	0.2158	0.2042
Echinodermata	Asteroidea	*Ctenodiscus crispatus*	80	46.90	-59.10	10.256	0.0522	0.2230	0.2077
Echinodermata	Asteroidea	*Pisaster giganteus*	10	34.39	-119.68	16.850	0.0430	0.2030	0.1995
Echinodermata	Asteroidea	*Unidentified*	5	24.89	-80.99	10.412	0.0438	0.2048	0.2005
Echinodermata	Asteroidea	*Asterias vulgaris*	10	44.79	-66.92	12.237	0.0491	0.2149	0.2037
Echinodermata	Asteroidea	*Asterias acervata borealis*	40	43.58	-65.17	12.443	0.0495	0.2158	0.2042
Echinodermata	Asteroidea	*Asterias forbesi*	10	41.42	-70.80	9.635	0.0485	0.2133	0.2029
Echinodermata	Asteroidea	*Odontaster hispidus*	40	41.30	-70.80	13.070	0.0466	0.2082	0.2004
Echinodermata	Asteroidea	*Plutonaster agassizii*	10	41.30	-70.80	13.991	0.0455	0.2052	0.1988
Echinodermata	Asteroidea	*Pontaster tenuispinus*	40	41.30	-70.80	11.963	0.0466	0.2082	0.2004
Echinodermata	Asteroidea	*Leptasterias compta*	100	40.28	-69.85	12.979	0.0463	0.2075	0.2000
Echinodermata	Asteroidea	*Benthopecten spinosus*	100	39.25	-68.13	12.317	0.0478	0.2114	0.2020
Echinodermata	Asteroidea	*Astropecten articulatus*	200	35.71	-73.50	10.612	0.0478	0.2114	0.2020
Echinodermata	Asteroidea	*Urasterias linckii*	200	35.71	-73.50	10.348	0.0478	0.2114	0.2020
Echinodermata	Asteroidea	*Asterias tanneri*	200	35.71	-73.50	15.090	0.0478	0.2114	0.2020
Echinodermata	Asteroidea	*Asterina miniata*	10	35.20	-121.30	12.135	0.0478	0.2114	0.2020
Echinodermata	Asteroidea	*Astropecten americanus*	10	26.90	-82.80	11.975	0.0448	0.2033	0.1979
Echinodermata	Asteroidea	*Asterina minuta*	15	18.04	-67.96	9.692	0.0468	0.2087	0.2006
Echinodermata	Asteroidea	*Linckia guildingii*	30	18.04	-67.96	11.780	0.0453	0.2047	0.1986
Echinodermata	Asteroidea	*Acanthaster planci*	25	5.86	-162.08	15.441	0.0432	0.1992	0.1958
Echinodermata	Asteroidea	*Ctenodiscus procurator*	30	-35.70	-72.80	16.547	0.0437	0.2004	0.1965
Echinodermata	Crinoidea	*Heliometra glacialis*	20	68.20	39.20	11.082	0.0499	0.2169	0.2047
Echinodermata	Crinoidea	*Ptilocrinus pinnatus*	10	53.10	-130.00	9.254	0.0498	0.2166	0.2045
Echinodermata	Crinoidea	*Florometra asperrima*	12	47.10	-124.20	11.013	0.0479	0.2116	0.2020
Echinodermata	Crinoidea	*Bythocrinus robustus*	40	42.30	-70.77	10.922	0.0455	0.2052	0.1988
Echinodermata	Crinoidea	*Psathyrometra fragilis*	20	35.07	139.70	11.826	0.0436	0.2002	0.1963
Echinodermata	Crinoidea	*Pentametrocrinus japonicus*	20	34.90	138.50	11.758	0.0455	0.2052	0.1988
Echinodermata	Crinoidea	*Crinometra concinna*	40	28.05	-96.02	12.945	0.0460	0.2065	0.1995
Echinodermata	Crinoidea	*Isocrinus decorus*	50	21.40	-76.70	13.582	0.0468	0.2086	0.2006
Echinodermata	Crinoidea	*Endoxocrinus parra*	60	21.40	-76.70	14.717	0.0431	0.1988	0.1956
Echinodermata	Crinoidea	*Tropiometra picta*	30	21.40	-76.70	14.161	0.0431	0.1988	0.1956
Echinodermata	Crinoidea	*Promachocrinus kerguelensis*	20	11.17	-60.68	13.571	0.0431	0.1988	0.1956
Echinodermata	Crinoidea	*Capillaster multiradiata*	30	7.85	116.90	11.838	0.0431	0.1988	0.1956
Echinodermata	Crinoidea	*Pachylometra patula*	30	7.85	116.90	12.888	0.0431	0.1988	0.1956
Echinodermata	Crinoidea	*Catoptometra ophiura*	30	7.85	116.90	14.320	0.0431	0.1988	0.1956
Echinodermata	Crinoidea	*Hypalocrinus naresianus*	30	7.85	116.90	13.582	0.0442	0.2016	0.1971
Echinodermata	Crinoidea	*Parametra granulata*	30	7.85	116.90	13.502	0.0442	0.2016	0.1971
Echinodermata	Crinoidea	*Craspedometra anceps*	30	7.85	116.90	13.673	0.0442	0.2016	0.1971
Echinodermata	Crinoidea	*Zygometra microdiscus*	40	-5.99	134.10	15.904	0.0449	0.2036	0.1980
Echinodermata	Crinoidea	*Tropiometra carinata*	15	-22.98	-43.20	9.197	0.0437	0.2005	0.1965
Echinodermata	Crinoidea	*Pilometra müllerі*	20	-33.85	151.26	15.486	0.0432	0.1990	0.1957

Echinodermata	Crinoidea	*Bathycrinus sp.*	3100	8.70	-55.80	0.0515	0.2210	0.2075	0.0515
Echinodermata	Crinoidea	*Bathycrinus sp.*	3100	8.70	-55.80	0.0515	0.2210	0.2075	0.0515
Echinodermata	Echinoidea	*Strongylocentrotus droebachiensis*	40	64.00	-38.00	7.033	0.0498	0.2166	0.2046
Echinodermata	Echinoidea	*Echinarachnius parma*	32	59.20	-165.80	7.195	0.0494	0.2155	0.2040
Echinodermata	Echinoidea	*Arbacia pustulosa*	15	40.76	14.35	8.643	0.0490	0.2145	0.2035
Echinodermata	Echinoidea	*Echinus esculentus*	10	38.00	-1.02	7.358	0.0438	0.2006	0.1965
Echinodermata	Echinoidea	*Paracentrotus lividus*	5	37.24	13.68	9.830	0.0431	0.1988	0.1956
Echinodermata	Echinoidea	*Clypeaster testudinarius*	20	33.40	134.60	9.968	0.0466	0.2083	0.2004
Echinodermata	Echinoidea	*Prionocidaris baculosa*	15	28.02	34.97	10.325	0.0494	0.2155	0.2040
Echinodermata	Echinoidea	*Tetrocidaris affinis*	10	26.90	-82.80	10.853	0.0440	0.2013	0.1969
Echinodermata	Echinoidea	*Mellita sexiesperforatus*	30	18.04	-67.96	12.089	0.0490	0.2145	0.2035
Echinodermata	Echinoidea	*Tetrapygus niger*	20	-9.40	-78.50	14.229	0.0443	0.2020	0.1972
Echinodermata	Echinoidea	*Heterocentrotus mammillatus*	20	-27.64	-144.33	12.420	0.0449	0.2036	0.1981
Echinodermata	Echinoidea	*Lytechinus albus*	10	-43.60	-74.00	13.832	0.0431	0.1988	0.1956
Echinodermata	Echinoidea	*Strongylocentrotus purpuratus*	10	34.80	-120.60	2.829	0.0443	0.2060	0.2013
Echinodermata	Echinoidea	*Strongylocentrotus purpuratus*	10	37.80	-122.10	6.438	0.0441	0.2054	0.2009
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	237	-60.62	-46.96	2.892	0.0513	0.2208	0.2074
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	602	-74.66	-29.52	2.281	0.0511	0.2203	0.2073
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	810	-75.54	-29.88	2.020	0.0517	0.2214	0.2076
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1480	-73.48	-22.66	1.932	0.0513	0.2207	0.2074
Echinodermata	Echinoidea	*Eucidaris tribuloides*	5	24.65	-81.25	4.863	0.0431	0.2033	0.1997
Echinodermata	Echinoidea	*unidentified Echinoid*	5	24.65	-81.25	4.829	0.0431	0.2033	0.1997
Echinodermata	Echinoidea	*unidentified Echinoid*	5	24.65	-81.25	10.569	0.0431	0.2033	0.1997
Echinodermata	Echinoidea	*Lytechinus varieqatus*	5	24.79	-80.82	5.727	0.0431	0.2033	0.1997
Echinodermata	Ophiuroidea	*Astrophyton* sp.	60	56.00	2.90	11.116	0.0485	0.2133	0.2029
Echinodermata	Ophiuroidea	*Ophiopholis aculeata japonica*	10	53.91	-166.50	9.807	0.0447	0.2032	0.1979
Echinodermata	Ophiuroidea	*Gorgonocephalus arcticus*	10	41.50	-70.30	9.370	0.0490	0.2146	0.2036
Echinodermata	Ophiuroidea	*Ophioglypha sarsii*	100	39.54	-72.35	15.498	0.0447	0.2032	0.1979
Echinodermata	Ophiuroidea	*Gorgonocephalus eucnemis*	50	38.30	139.00	10.635	0.0488	0.2139	0.2032
Echinodermata	Ophiuroidea	*Ophionereis eurybrachiplax*	50	38.30	139.00	11.471	0.0449	0.2035	0.1980
Echinodermata	Ophiuroidea	*Ophioglypha lütkeni*	200	35.20	-121.30	9.635	0.0463	0.2075	0.2000
Echinodermata	Ophiuroidea	*Ophiothrix angulata*	200	21.40	-76.70	11.872	0.0476	0.2109	0.2017
Echinodermata	Ophiuroidea	*Ophiocamax fasciculata*	100	21.40	-76.70	8.250	0.0448	0.2033	0.1979
Echinodermata	Ophiuroidea	*Ophiocoma erinaceus*	20	20.10	-155.30	16.287	0.0448	0.2033	0.1979
Echinodermata	Ophiuroidea	*Unidentified Ophiuroid*	5	25.01	-80.46	13.622	0.0431	0.2033	0.1997
Echinodermata	Ophiuroidea	*Unidentified Ophiuroid*	5	24.65	-81.25	13.709	0.0431	0.2033	0.1997
Echinodermata	Ophiuroidea	*Ophioderma cinerum*	30	18.50	-66.60	16.828	0.0448	0.2033	0.1979
Echinodermata	Ophiuroidea	*Ophiocoma aethiops*	25	18.04	-67.96	15.034	0.0448	0.2033	0.1979
Echinodermata	Ophiuroidea	*Ophiomixa flaccida*	120	18.04	-67.96	13.991	0.0435	0.2000	0.1963
Echinodermata	Ophiuroidea	*Ophiocoma pumila*	120	18.04	-67.96	13.571	0.0445	0.2025	0.1975
Echinodermata	Ophiuroidea	*Ophiomusium lymani*	200	-1.00	-91.01	7.752	0.0500	0.2173	0.2049

Echinodermata	Ophiuroidea	*Ophioglypha lymani*	30	-35.70	-72.80	8.920	0.0445	0.2025	0.1975
Coralline algae	-	*Lithothamnium* sp.	10	78.00	20.00	10.129	0.0495	0.2158	0.2042
Coralline algae	-	*Lithothamnium soriferum*	10	75.00	20.00	11.151	0.0508	0.2192	0.2059
Coralline algae	-	*Lithothamnium glaciale*	10	75.00	20.00	15.283	0.0452	0.2045	0.1985
Coralline algae	-	*Lithothamnium fornicatum*	10	72.00	20.00	11.758	0.0495	0.2158	0.2042
Coralline algae	-	*Lithothamnium polymorphum*	10	57.00	12.00	10.623	0.0494	0.2155	0.2040
Coralline algae	-	*Corallina squamata* - 29-Nov	5	50.60	-2.30	14.002	0.0475	0.2106	0.2016
Coralline algae	-	*Corallina squamata* - 29-Jan	5	50.60	-2.30	13.980	0.0476	0.2108	0.2016
Coralline algae	-	*Corallina squamata* - 26-Mar	5	50.60	-2.30	12.956	0.0475	0.2107	0.2016
Coralline algae	-	*Corallina squamata* - 28-May	5	50.60	-2.30	12.717	0.0480	0.2118	0.2021
Coralline algae	-	*Corallina squamata* - 01-Jul	5	50.60	-2.30	11.460	0.0466	0.2083	0.2004
Coralline algae	-	*Corallina squamata* - 13-Aug	5	50.60	-2.30	9.531	0.0476	0.2109	0.2017
Coralline algae	-	*Corallina squamata* - 12-Sep	5	50.60	-2.30	27.269	0.0429	0.1982	0.1953
Coralline algae	-	*Corallina squamata* - 10-Oct	5	50.60	-2.30	26.986	0.0429	0.1982	0.1953
Coralline algae	-	*Corallina officinalis*	5	49.60	-1.20	26.158	0.0429	0.1982	0.1953
Coralline algae	-	*Lithothamnium calcareum*	10	48.08	-4.00	17.805	0.0429	0.1982	0.1953
Coralline algae	-	*Lithophyllum incrustans*	10	48.00	-3.00	22.049	0.0445	0.2027	0.1976
Coralline algae	-	*Phymatolithon compactum*	10	48.00	-55.00	20.085	0.0445	0.2027	0.1976
Coralline algae	-	*Lithophyllum tortuosum*	20	44.00	9.00	18.612	0.0433	0.1995	0.1960
Coralline algae	-	*Lithophyllum proboscideum*	15	37.00	-122.00	19.338	0.0439	0.2010	0.1967
Coralline algae	-	*Goniolithon strictum* - old	30	25.00	-75.00	15.915	0.0415	0.1945	0.1935
Coralline algae	-	*Goniolithon strictum* - old	30	25.00	-75.00	15.814	0.0429	0.1982	0.1954
Coralline algae	-	*Goniolithon strictum* - young	30	25.00	-75.00	19.516	0.0434	0.1997	0.1961
Coralline algae	-	*Lithophyllum pachydermum*	30	25.00	-75.00	15.170	0.0431	0.1990	0.1957
Coralline algae	-	*Goniolithon acropectum*	20	18.00	-68.00	20.863	0.0433	0.1994	0.1959
Coralline algae	-	*Amphiroa fragilissima*	10	18.00	-68.00	7.114	0.0437	0.2004	0.1965
Coralline algae	-	*Lithothamnium nodosum*	5	0.00	-90.00	12.260	0.0472	0.2098	0.2012
Coralline algae	-	*Lithophyllum oncodes*	30	-7.00	56.00	11.254	0.0472	0.2098	0.2012
Coralline algae	-	*Goniolithon orthoblastum*	10	-10.00	145.00	10.807	0.0472	0.2098	0.2012
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	20.10	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	20.30	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	17.20	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	18.40	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	21.50	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	22.70	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	22.80	0.0428	0.2027	0.1993
Coralline algae	-	*Amphiroa rigida*	5	24.89	-80.99	22.00	0.0428	0.2027	0.1993
Coralline algae	-	*Neogoniolithon sp.*	5	24.89	-80.99	16.90	0.0428	0.2027	0.1993
Coralline algae	-	*Neogoniolithon sp.*	5	24.89	-80.99	19.40	0.0428	0.2027	0.1993
Coralline algae	-	*Neogoniolithon sp.*	5	24.89	-80.99	18.80	0.0428	0.2027	0.1993

Coralline algae	-	*Neogoniolithon sp.*	5	24.89	-80.99	17.10	0.0428	0.2027	0.1993
Coralline algae	-	*Neogoniolithon sp.*	5	24.89	-80.99	15.20	0.0428	0.2027	0.1993
Coralline algae	-	*Lithothamnium erubescens*	10	-10.00	123.00	10.129	0.0472	0.2098	0.2012
Coralline algae	-	*Archaeolithothamium episporum*	10	-10.00	80.00	10.899	0.0472	0.2098	0.2012
Coralline algae	-	*Lithothamnium kaiseri*	10	-15.00	-172.00	11.414	0.0472	0.2098	0.2012
Coralline algae	-	*Porolithon craspedium*	10	-15.00	-172.00	12.043	0.0472	0.2098	0.2012
Coralline algae	-	*Porolithon oncodes*	10	-15.00	-172.00	11.872	0.0472	0.2098	0.2012
Foraminifera	-	*Pulvinulina menardii* - pelagic	20	40.56	-66.15	4.328	0.0448	0.2034	0.1979
Foraminifera	-	*Polytrema mineaccum* - benthic	100	25.00	-77.00	2.118	0.0429	0.1983	0.1954
Foraminifera	-	*Orbitolites marginatis* - benthic	50	24.60	-81.96	5.765	0.0431	0.1989	0.1957
Foraminifera	-	*Amphistegina lessonii* - pelagic	20	16.10	-22.95	14.524	0.0442	0.2016	0.1971
Foraminifera	-	*Sphaeroidina dehiscens* - pelagic	20	12.40	121.60	12.283	0.0440	0.2011	0.1968
Foraminifera	-	*Orbitolites complanata* - benthic	30	-17.30	177.47	10.887	0.0440	0.2011	0.1968
Foraminifera	-	*Archais sp.*	5	24.59	-81.54	15.20	0.0431	0.2033	0.1997
Foraminifera	-	*Archais sp.*	5	24.59	-81.54	13.40	0.0431	0.2033	0.1997
Foraminifera	-	*Archais sp.*	5	24.59	-81.54	13.80	0.0431	0.2033	0.1997
Foraminifera	-	*Archais sp.*	5	24.59	-81.54	14.60	0.0431	0.2033	0.1997
Foraminifera	-	*Globigerinoides ruber*	5	11.84	-86.68	0.59	0.0417	0.2000	0.1976
Foraminifera	-	*Globigerinoides ruber*	5	11.95	-86.68	0.69	0.0417	0.2000	0.1976
Foraminifera	-	*Globigerinoides sacculifer*	5	11.95	-86.68	0.50	0.0417	0.2000	0.1976
Foraminifera	-	*Globorotalia menardii*	5	25.03	-77.83	0.55	0.0413	0.1993	0.1971
Foraminifera	-	*Hastigeria pelagica*	5	11.95	-86.68	0.67	0.0417	0.2000	0.1976
Foraminifera	-	*Orbulina universa*	5	11.95	-86.68	0.75	0.0417	0.2000	0.1976
Hydrocorallia	-	*Millepora alcicornis*	10	24.60	-81.96	1.126	0.0442	0.2016	0.1971
Hydrocorallia	-	*Distichopora nitida*	20	7.40	151.50	1.516	0.0440	0.2011	0.1968
Hydrocorallia	-	*Millepora braziliensis*	30	-12.20	-36.80	0.285	0.0432	0.1990	0.1958
Hexacorallia	-	*Madracis decactis*	20	32.40	-64.90	1.315	0.0440	0.2011	0.1968
Hexacorallia	-	*Siderastrea radians*	20	32.40	-64.90	1.031	0.0440	0.2011	0.1968
Hexacorallia	-	*Flabellum alabastrum*	10	26.00	-77.20	0.463	0.0440	0.2011	0.1968
Hexacorallia	-	*Acropora cervicornis*	15	26.00	-77.20	0.747	0.0440	0.2011	0.1968
Hexacorallia	-	*Favia fragum*	20	24.60	-81.96	0.439	0.0440	0.2011	0.1968
Hexacorallia	-	*Dasmosmilia lymani*	10	24.60	-81.96	0.901	0.0455	0.2052	0.1989
Hexacorallia	-	*Balanophyllia floridana*	10	24.54	-81.80	0.640	0.0440	0.2012	0.1969
Hexacorallia	-	*Paracyathus defilipii*	10	24.54	-81.80	0.534	0.0448	0.2033	0.1979
Hexacorallia	-	*Porites lutea*	2	24.55	124.33	4.85	0.0416	0.1998	0.1974
Hexacorallia	-	*Porites sp.*	2	-18.28	147.38	3.97	0.0424	0.2016	0.1986
Hexacorallia	-	*Deltocyathus italicus*	20	18.50	-63.51	0.569	0.0455	0.2052	0.1989
Hexacorallia	-	*Desmophyllum ingens*	15	-36.55	-73.00	0.700	0.0519	0.2223	0.2074

Octocorallia	-	*Gorgonia* sp.	30	54.60	154.40	0.415	0.0431	0.1988	0.1956
Octocorallia	-	*Alcyonium carneum*	50	45.18	-55.85	14.195	0.0432	0.1991	0.1958
Octocorallia	-	*Paramuricea borealis*	50	45.18	-55.85	13.434	0.0448	0.2033	0.1979
Octocorallia	-	*Alcyonium carneum*	50	45.18	-55.85	9.024	0.0512	0.2205	0.2065
Octocorallia	-	*Pennatula aculeata*	50	44.45	-58.51	15.554	0.0430	0.1986	0.1956
Octocorallia	-	*Paragorgia arborea*	50	44.36	-63.75	15.509	0.0448	0.2033	0.1979
Octocorallia	-	*Paragorgia arborea*	50	43.00	-62.00	10.841	0.0479	0.2116	0.2020
Octocorallia	-	*Corallium elatior*	40	42.25	130.91	7.810	0.0494	0.2157	0.2041
Octocorallia	-	*Primnoa resedaeformis*	30	42.25	130.91	15.960	0.0458	0.2061	0.1993
Octocorallia	-	*Primnoa reseda*	40	42.25	-63.25	6.719	0.0450	0.2038	0.1982
Octocorallia	-	*Rhipidogorgia flabellum*	20	32.40	-64.90	8.261	0.0450	0.2038	0.1982
Octocorallia	-	*Pleurocorallium johnsoni*	30	25.75	-20.20	8.562	0.0450	0.2038	0.1982
Octocorallia	-	*Gorgonia acerosa*	50	24.60	-81.96	9.347	0.0450	0.2038	0.1982
Octocorallia	-	*Leptogorgia pulchra*	80	24.60	-108.25	14.660	0.0436	0.2001	0.1963
Octocorallia	-	*Xiphigorgia anceps*	20	24.47	-81.55	14.252	0.0446	0.2030	0.1977
Octocorallia	-	*Eunicella singularis*	20	42.58	8.75	2.11	0.0457	0.2089	0.2028
Octocorallia	-	*Eunicella cavolini*	20	42.58	8.75	2.45	0.0457	0.2089	0.2028
Octocorallia	-	*Paramuricea clavata*	20	42.58	8.75	2.45	0.0457	0.2089	0.2028
Octocorallia	-	*Corallium rubrum*	60	42.41	8.75	3.49	0.0457	0.2089	0.2028
Octocorallia	-	*E. Barbadensis*	10	11.32	-60.7	5.90	0.0411	0.1987	0.1967
Octocorallia	-	*Lepidisis spp.*	3945	-45.37	144.57	8.90	0.0517	0.2215	0.2076
Octocorallia	-	*Tubipora musica*	5	14.21	122.06	15.60	0.0419	0.2005	0.1979
Octocorallia	-	*Tubipora musica*	5	14.21	122.06	13.90	0.0419	0.2005	0.1979
Octocorallia	-	*Tubipora musica*	5	14.21	122.06	13.00	0.0419	0.2005	0.1979
Octocorallia	-	*Plexaurella grisea*	10	11.32	-60.59	18.10	0.0411	0.1986	0.1966
Octocorallia	-	*Ellisella barbadensis*	10	11.32	-60.59	14.60	0.0411	0.1986	0.1966
Octocorallia	-	*Muricea echinata*	10	22.86	-106.10	9.393	0.0478	0.2114	0.2019
Octocorallia	-	*Leptogorgia rigida*	150	22.86	-109.79	10.566	0.0486	0.2135	0.2030
Octocorallia	-	*Heliopora cerulea*	20	12.40	121.60	15.113	0.0445	0.2026	0.1975
Octocorallia	-	*Tubipora purpurea*	10	1.33	103.83	14.660	0.0449	0.2035	0.1980
Octocorallia	-	*Phyllogorgia quercifolia*	10	-3.83	-32.41	7.079	0.0500	0.2171	0.2048
Octocorallia	-	*Ctenocella pectinata*	20	-10.00	142.20	10.841	0.0436	0.2002	0.1963
Octocorallia	-	*Muricea humilis*	30	-12.20	-36.80	7.253	0.0466	0.2082	0.2004
Octocorallia	-	*Gorgonia subfruticosa*	45	-18.00	-178.00	7.810	0.0466	0.2082	0.2004
Octocorallia	-	*Plexaurella grandiflora*	20	-28.40	155.67	10.566	0.0466	0.2082	0.2004
Octocorallia	-	*Eunicella papillose*	30	-34.21	18.35	15.870	0.0468	0.2086	0.2006
Octocorallia	-	*Eunicella alba*	30	-34.22	18.48	16.344	0.0479	0.2118	0.2021
Octocorallia	-	*Eunicella tricoronata*	30	-34.22	18.48	18.052	0.0429	0.1982	0.1953
Octocorallia	-	*Lophogorgia flamea*	30	-34.22	18.48	18.142	0.0475	0.2107	0.2016

Bryozoa	-	*Flustra membranacea*	50	59.17	-151.60	0.747	0.0514	0.2210	0.2068
Bryozoa	-	*Cellepora incrassata*	50	44.69	-62.69	1.315	0.0458	0.2061	0.1993
Bryozoa	-	*Schizoporella unicornis*	10	41.35	-70.79	7.126	0.0514	0.2210	0.2068
Bryozoa	-	*Bugula turrita*	40	41.23	-70.07	8.134	0.0508	0.2193	0.2059
Bryozoa	-	*Lepralia* sp.	20	40.80	14.20	5.905	0.0463	0.2075	0.2000
Bryozoa	-	*Amathia spiralis*	20	35.22	-75.60	3.060	0.0478	0.2114	0.2020
Bryozoa	-	*Holoporella albirostris*	20	24.47	-81.55	11.162	0.0478	0.2114	0.2020
Bryozoa	-	*Bugula neritina*	20	24.47	-81.55	11.872	0.0514	0.2210	0.2068
Bryozoa	-	*Microporella grisea*	20	-28.40	155.67	12.888	0.0478	0.2114	0.2020
Bryozoa	-	*Adeonellopsis sp.*	12	-45.3	166.91	10.265	0.0458	0.2092	0.2029
Bryozoa	-	*Bugula neritina*	5	26.71	-79.99	9.730	0.0422	0.2012	0.1983
Bryozoa	-	*Bugula neritina*	5	26.88	-79.99	11.700	0.0422	0.2012	0.1983
Brachiopoda	-	*Terebratulina septentrionalis*	30	44.87	-66.91	1.622	0.0448	0.2034	0.1979
Brachiopoda	-	*Laqueus californicus*	80	24.60	-108.25	0.806	0.0465	0.2078	0.2002
Brachiopoda	-	*Krassina rubra*	5	-34.25	18.35	0.920	0.0466	0.2110	0.2038
Brachiopoda	-	*Megerlea truncata*	5	37.28	13.07	2.930	0.0424	0.2017	0.1986
Brachiopoda	-	*Notosaris sp.*	5	-42.94	168.69	2.580	0.0451	0.2077	0.2022
Brachiopoda	-	*Terebratella cruenta*	5	-42.84	168.69	0.750	0.0451	0.2077	0.2022
Brachiopoda	-	*Stethothyris sp.*	5	-64.03	-61.82	0.690	0.0514	0.2209	0.2074
Brachiopoda	-	*Thecidellina sp.*	5	12.31	-68.97	8.920	0.0426	0.2021	0.1989
Brachiopoda	-	*Thecidellina sp.*	5	12.21	-68.97	9.370	0.0426	0.2021	0.1989
Mollusca	Amphineura	*Mopalia muscosa*	120	34.39	-119.70	0.190	0.0401	0.1908	0.1916
Mollusca	Bivalvia	*Astarte borealis*	50	74.16	54.40	7.068	0.0467	0.2083	0.2004
Mollusca	Bivalvia	*Tellina calcarea*	40	74.16	54.33	1.918	0.0431	0.1989	0.1957
Mollusca	Bivalvia	*Pecten groenlandicus*	20	73.50	68.83	1.185	0.0451	0.2041	0.1983
Mollusca	Bivalvia	*Pecten islandicus*	40	71.50	47.00	0.866	0.0442	0.2019	0.1972
Mollusca	Bivalvia	*Pecten dislocatus*	10	26.81	-82.29	1.516	0.0494	0.2156	0.2041
Mollusca	Bivalvia	*Pecten ventricosus*	10	22.86	-106.10	0.948	0.0495	0.2158	0.2042
Mollusca	Bivalvia	*Placuna orbicularis*	10	16.83	120.26	0.735	0.0504	0.2182	0.2054
Mollusca	Cephalopoda	*Nautilus pompilius*	100	8.53	123.03	0.830	0.0430	0.1985	0.1955
Mollusca	Cephalopoda	*Sepia officinalis*	10	5.84	118.27	0.842	0.0519	0.2223	0.2074
Mollusca	Cephalopoda	*Argonauta argo*	50	-35.82	175.39	0.534	0.0486	0.2136	0.2030
Mollusca	Gastropoda	*Neptunea despecta*	20	69.63	57.35	0.996	0.0494	0.2155	0.2040
Mollusca	Gastropoda	*Natica clausa*	20	60.50	-46.91	0.889	0.0449	0.2035	0.1980
Mollusca	Gastropoda	*Tachyrhynchus erosa*	30	52.90	158.76	1.929	0.0449	0.2035	0.1980
Mollusca	Gastropoda	*Nassa tegula*	20	36.62	-121.91	2.943	0.0447	0.2032	0.1979
Mollusca	Gastropoda	*Odontocymbiola magellanica*	15	-42.71	-65.02	15.608	0.0488	0.2155	0.2057
Mollusca	Gastropoda	*Nassa isculpta*	50	32.34	-118.43	2.495	0.0447	0.2030	0.1978
Mollusca	Scaphopoda	*Dentalium solidum*	30	41.23	-70.07	2.637	0.0487	0.2137	0.2031

Crustacea	Cirripedia	*Scalpellum regium*	5	52.92	-132.29	0.237	0.0449	0.2035	0.1980
Crustacea	Cirripedia	*Balanus hameri*	20	41.23	-70.07	0.439	0.0468	0.2087	0.2006
Crustacea	Cirripedia	*Balanus amphitrite*	5	38.92	-74.91	2.106	0.0476	0.2109	0.2017
Crustacea	Cirripedia	*Lepas anatifera*	10	24.47	-81.55	1.209	0.0489	0.2142	0.2034
Crustacea	Cirripedia	*Mitella polymerus*	10	22.86	-106.10	1.386	0.0515	0.2213	0.2069
Crustacea	Amphipoda	*Tryphosa pinguis*	30	41.52	-70.67	9.381	0.0485	0.2133	0.2029
Crustacea	Isopoda	*Pentidotea wosnesenkii*	2	48.75	-125.23	6.880	0.0467	0.2111	0.2038
Crustacea	Isopoda	*Sphaeroma serratum*	2	45.18	13.68	5.640	0.0473	0.2124	0.2044
Crustacea	Isopoda	*Gnovimosphaeroma oregonensis*	2	48.75	-125.23	5.560	0.0467	0.2111	0.2038
Crustacea	Decapoda	*Crago dalli*	40	59.17	-151.60	6.812	0.0504	0.2184	0.2055
Crustacea	Decapoda	*Pagurus rathbuni*	210	58.46	-175.22	14.592	0.0447	0.2032	0.1979
Crustacea	Decapoda	*Homarus americanus* - small	30	43.84	-69.64	11.712	0.0491	0.2149	0.2037
Crustacea	Decapoda	*Homarus americanus* - medium	30	43.84	-69.64	9.462	0.0466	0.2082	0.2004
Crustacea	Decapoda	*Homarus americanus* - large	30	43.84	-69.64	7.253	0.0442	0.2018	0.1971
Crustacea	Decapoda	*Homarus americanus*	50	41.35	-70.79	10.106	0.0485	0.2133	0.2029
Crustacea	Decapoda	*Libinia emarginata*	20	41.35	-70.79	10.175	0.0478	0.2114	0.2020
Crustacea	Decapoda	*Munida iris*	20	37.62	-76.26	9.058	0.0478	0.2114	0.2019
Crustacea	Decapoda	*Pandalus platyceros*	50	36.62	-121.91	9.496	0.0485	0.2133	0.2029
Crustacea	Decapoda	*Palinurus argus*	60	21.84	-71.33	10.244	0.0485	0.2133	0.2029
Crustacea	Decapoda	*Grapsus grapsus*	60	-9.36	46.40	18.433	0.0485	0.2133	0.2029
Crustacea	Stomatopoda	*Chloridella empusa*	20	24.47	-81.55	5.695	0.0485	0.2133	0.2029

[a] Corrections used from the CO2SYS Matlab script equations. For Mg-calcite, corrections applied from pure calcite. See text for details.

[b] Calculations.done using correlation equations. See text for details.

[c] Solubility -log IAP_i divided as "cleaned" and "minimally prepared" curves.

Table S3. Details of sample collection and skeletal material used.

Taxa	Class	Species	*n*	Depth (m)	Lat.	Long.	Location	Material	Collection	Reference
Echinodermata	Asteroidea	*Labidiaster annulatus*	9	175	-61.21	-56.01	Elephant Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Macroptychaster accrescens*	3	180	-63.53	-62.75	Low Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Paralophaster godfroyi*	1	180	-63.53	-62.75	Low Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Paralophaster* sp.	3	180	-63.53	-62.75	Low Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Perknaster* sp.	2	180	-63.53	-62.75	Low Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Acodontaster hodgsoni*	3	160	-64.15	-62.74	Dallmann Bay (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Kampylaster incurvatus*	4	160	-64.15	-62.74	Dallmann Bay (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Odontaster penicillatus*	1	160	-64.15	-62.74	Dallmann Bay (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Porania antarctica*	3	160	-64.15	-62.74	Dallmann Bay (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Diplasterias brandti*	3	30	-64.77	-64.05	Arthur Harbor (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Granaster nutrix*	5	30	-64.77	-64.05	Arthur Harbor (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Neosmilaster georgianus*	3	30	-64.77	-64.05	Arthur Harbor (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Odontaster meridionalis*	3	30	-64.77	-64.04	SE Boneparte Pt. (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Perknaster aurorae*	3	30	-64.78	-63.99	Stepping Stones (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Acodontaster conspicuus*	1	30	-65.07	-63.97	Lemaire Channel (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Perknaster fuscus antracticus*	1	30	-65.07	-63.97	Lemaire Channel (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Asteroidea	*Henricia* sp.	2	155	-65.67	-67.40	Renaud Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Asteroidea	*Diplopteraster verrucosus*	2	900	-66.29	-66.60	Banana Trench (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Echinoidea	*Diadema setosum*	3	0.5	-18.85	159.75	Aitukai Island (Pacific Ocean)	Spines	Manual	NEW
Echinodermata	Echinoidea	*Evechinus chloroticus*	3	5	-45.30	166.97	Doubtful Sound (Pacific Ocean)	Plates	Scuba diving	NEW
Echinodermata	Echinoidea	*Pseudechinus huttoni*	2	8	-45.41	167.10	Doubtful Sound (Pacific Ocean)	Spines	Scuba diving	NEW
Echinodermata	Echinoidea	*Pseudechinus huttoni*	3	8	-45.41	167.10	Doubtful Sound (Pacific Ocean)	Plates	Trawling	NEW
Echinodermata	Echinoidea	*Amphineustes similis*	2	685	-64.75	-65.47	Hugo Island (Southern Ocean)	Spines	Trawling	NEW
Echinodermata	Echinoidea	*Amphineustes similis*	4	685	-64.75	-65.47	Hugo Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Echinoidea	*Ctenocidaris perrieri*	3	685	-64.75	-65.47	Hugo Island (Southern Ocean)	Spines	Trawling	NEW
Echinodermata	Echinoidea	*Ctenocidaris perrieri*	3	685	-64.75	-65.47	Hugo Island (Southern Ocean)	Plates	Trawling	NEW
Echinodermata	Echinoidea	*Sterechinus neumayeri*	3	30	-65.07	-63.97	Lemaire Channel (Southern Ocean)	Spines	Scuba diving	NEW
Echinodermata	Echinoidea	*Sterechinus neumayeri*	6	30	-65.07	-63.97	Lemaire Channel (Southern Ocean)	Plates	Scuba diving	NEW
Echinodermata	Echinoidea	*Sterechinus neumayeri*	3	30	-65.07	-63.97	Lemaire Channel (Southern Ocean)	Spines	Scuba diving	NEW
Echinodermata	Ophiuroidea	*Ophionotus victoriae*	3	30	-64.77	-64.05	Arthur Harbor (Southern Ocean)	Plates	Manual	NEW
Echinodermata	Ophiuroidea	*Ophiosparte gigas*	1	30	-64.77	-64.05	Arthur Harbor (Southern Ocean)	Plates	Benthic trawl	NEW
Echinodermata	Asteroidea	*Asterias linckii*	1	20	65.81	39.73	White Sea (Arctic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Orthasterias tanneri*	1	30	61.68	3.31	Norwegian Sea (Atlantic Ocean)	Plates	see original reference	Samoilov & Terentieva, 1925
Echinodermata	Asteroidea	*Ctenodiscus crispatus*	1	80	46.90	-59.10	Newfoundland (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Pisaster giganteus*	1	10	34.39	-119.68	Eastern Pacific	Plates	see original reference	Gayathri et al., 2007

Echinodermata	Asteroidea	*Unidentified*	1	5	24.89	-80.99	Florida Keys	Plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Asteroidea	*Asterias vulgaris*	1	10	44.79	-66.92	Eastport Maine (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Asterias acervata borealis*	1	40	43.58	-65.17	Nova Scotia (Atlantic Ocean)	Plates	see original reference	Schmelck, 1901
Echinodermata	Asteroidea	*Asterias forbesi*	1	10	41.42	-70.80	Vineyard Sound (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Odontaster hispidus*	1	40	41.30	-70.80	Martha's Vineyard (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Plutonaster agassizii*	1	10	41.30	-70.80	Martha's Vineyard (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Pontaster tenuispinus*	1	40	41.30	-70.80	Martha's Vineyard (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Leptasterias compta*	1	100	40.28	-69.85	Cape Cod (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Benthopecten spinosus*	1	100	39.25	-68.13	Cape Cod (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Astropecten articulatus*	1	200	35.71	-73.50	Cape Hatteras (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Urasterias linckii*	1	200	35.71	-73.50	Cape Hatteras (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Asterias tanneri*	1	200	35.71	-73.50	Cape Hatteras (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Asterina miniata*	1	10	35.20	-121.30	California (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Astropecten americanus*	1	10	26.90	-82.80	West Florida (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Asterina minuta*	1	15	18.04	-67.96	British West Indies (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Linckia guildingii*	1	30	18.04	-67.96	British West Indies (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Acanthaster planci*	1	25	5.86	-162.08	Palmyra Island (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Asteroidea	*Ctenodiscus procurator*	1	30	-35.70	-72.80	Chile (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Heliometra glacialis*	1	20	68.20	39.20	Kola Peninsula (Barents Sea)	Plates	see original reference	Terentieva, 1932
Echinodermata	Crinoidea	*Ptilocrinus pinnatus*	1	10	53.10	-130.00	British Columbia (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Florometra asperrima*	1	12	47.10	-124.20	Washington (Pacific ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Bythocrinus robustus*	1	40	42.30	-70.77	Massachussets (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Psathyrometra fragilis*	1	20	35.07	139.70	Japan Sea (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Pentametrocrinus japonicus*	1	20	34.90	138.50	Japan Sea (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Crinometra concinna*	1	40	28.05	-96.02	Gulf of Mexico (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Isocrinus decorus*	1	50	21.40	-76.70	Cuba (Caribbean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Endoxocrinus parra*	1	60	21.40	-76.70	Cuba (Caribbean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Tropiometra picta*	1	30	21.40	-76.70	Cuba (Caribbean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Promachocrinus kerguelensis*	1	20	11.17	-60.68	Tobago (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Capillaster multiradiata*	1	30	7.85	116.90	Philippines (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Pachylometra patula*	1	30	7.85	116.90	Philippines (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Catoptometra ophiura*	1	30	7.85	116.90	Philippines (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Hypalocrinus naresianus*	1	30	7.85	116.90	Philippines (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Parametra granulata*	1	30	7.85	116.90	Philippines (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Craspedometra anceps*	1	30	7.85	116.90	Philippines (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Zygometra microdiscus*	1	40	-5.99	134.10	New Guinea (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Tropiometra carinata*	1	15	-22.98	-43.20	Rio de Janeiro (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Pilometra mülleri*	1	20	-33.85	151.26	Sydney Harbor (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Crinoidea	*Bathycrinus sp.*	1	3100	8.70	-55.80	Demerara Plateau (Atlantic Ocean)	Plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Crinoidea	*Bathycrinus sp.*	1	3100	8.70	-55.80	Demerara Plateau (Atlantic Ocean)	Plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Echinoidea	*Strongylocentrotus droebachiensis*	1	40	64.00	-38.00	Greenland Sea (Atllantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922

Echinodermata	Echinoidea	*Echinarachnius parma*	1	32	59.20	-165.80	Bering Sea (Arctic Ocean)	Plates	see original reference	Terentieva, 1932
Echinodermata	Echinoidea	*Arbacia pustulosa*	1	15	40.76	14.35	Bay of Naples (Mediterranean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Echinus esculentus*	1	10	38.00	-1.02	Mediterranean Sea	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Paracentrotus lividus*	1	5	37.24	13.68	Sicily (Mediterranean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Clypeaster testudinarius*	1	20	33.40	134.60	South Japan Sea (Pacific Ocean)	Plates	see original reference	Terentieva, 1932
Echinodermata	Echinoidea	*Prionocidaris baculosa*	1	15	28.02	34.97	Red Sea	Plates	see original reference	Bütschli, 1908
Echinodermata	Echinoidea	*Tetrocidaris affinis*	1	10	26.90	-82.80	Florida (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Mellita sexiesperforatus*	1	30	18.04	-67.96	British West Indies (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Tetrapygus niger*	1	20	-9.40	-78.50	Peru (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Heterocentrotus mammillatus*	1	20	-27.64	-144.33	Tuamotu (Pacific Ocean)	Plates	see original reference	Terentieva, 1932
Echinodermata	Echinoidea	*Lytechinus albus*	1	10	-43.60	-74.00	Patagonia (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Echinoidea	*Strongylocentrotus purpuratus*	1	10	34.80	-120.60	California (Pacific Ocean)	Test/plates	see original reference	LaVigne *et al.*, 2013
Echinodermata	Echinoidea	*Strongylocentrotus purpuratus*	1	10	37.80	-122.10	California (Pacific Ocean)	Test/Plates	see original reference	LaVigne *et al.*, 2013
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	237	-60.62	-46.96	Antarctica	Plates	see original reference	Catarino *et al.*, 2013
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	602	-74.66	-29.52	Antarctica	Plates	see original reference	Catarino *et al.*, 2013
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	810	-75.54	-29.88	Antarctica	Plates	see original reference	Catarino *et al.*, 2013
Echinodermata	Echinoidea	*Ctenocidaris speciosa*	1	1480	-73.48	-22.66	Antarctica	Plates	see original reference	Catarino *et al.*, 2013
Echinodermata	Echinoidea	*Eucidaris tribuloides*	1	5	24.65	-81.25	Florida (Atlantic Ocean)	Test/plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Echinoidea	*unidentified Echinoid*	1	5	24.65	-81.25	Florida (Atlantic Ocean)	Test/plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Echinoidea	*unidentified Echinoid*	1	5	24.65	-81.25	Florida (Atlantic Ocean)	Test/plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Echinoidea	*Lytechinus varieqatus*	1	5	24.79	-80.82	Florida (Atlantic Ocean)	Test/plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Ophiuroidea	*Astrophyton* sp.	1	60	56.00	2.90	North Sea	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiopholis aculeata japonica*	1	10	53.91	-166.50	Unalaska (Arctic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Gorgonocephalus arcticus*	1	10	41.50	-70.30	Cape Cod (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophioglypha sarsii*	1	100	39.54	-72.35	New England slope (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Gorgonocephalus eucnemis*	1	50	38.30	139.00	Japan Sea (Pacific Ocean)	Plates	see original reference	Schmelck, 1901
Echinodermata	Ophiuroidea	*Ophionereis eurybrachiplax*	1	50	38.30	139.00	Japan Sea (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophioglypha lütkeni*	1	200	35.20	-121.30	California (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiothrix angulata*	1	200	21.40	-76.70	Cuba (Caribbean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiocamax fasciculata*	1	100	21.40	-76.70	Caribbean Sea	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiocoma erinaceus*	1	20	20.10	-155.30	Hawaii (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Unidentified Ophiuroid*	1	5	25.01	-80.46	Florida (Atlantic Ocean)	Test/plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Ophiuroidea	*Unidentified Ophiuroid*	1	5	24.65	-81.25	Florida (Atlantic Ocean)	Test/plates	see original reference	Carpenter & Lohmann, 1992
Echinodermata	Ophiuroidea	*Ophioderma cinerum*	1	30	18.50	-66.60	Puerto Rico (Caribbean Sea)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiocoma aethiops*	1	25	18.04	-67.96	Gulf of California (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiomixa flaccida*	1	120	18.04	-67.96	British West Indies (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiocoma pumila*	1	120	18.04	-67.96	British West Indies (Atlantic Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophiomusium lymani*	1	200	-1.00	-91.01	Galapagos (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Echinodermata	Ophiuroidea	*Ophioglypha lymani*	1	30	-35.70	-72.80	Chile (Pacific Ocean)	Plates	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Lithothamnium* sp.	1	10	78.00	20.00	Spitzbergen (Barents Sea)	Skeletal	see original reference	Högbom, 1894

Coralline algae	-	*Lithothamnium soriferum*	1	10	75.00	20.00	Spitzbergen (Barents Sea)	Skeletal	see original reference	Högbom, 1894
Coralline algae	-	*Lithothamnium glaciale*	1	10	75.00	20.00	Spitzbergen (Barents Sea)	Skeletal	see original reference	Högbom, 1894
Coralline algae	-	*Lithothamnium fornicatum*	1	10	72.00	20.00	Norwegian Sea	Skeletal	see original reference	Lemoine, 1910
Coralline algae	-	*Lithothamnium polymorphum*	1	10	57.00	12.00	North Sea	Skeletal	see original reference	Högbom, 1894
Coralline algae	-	*Corallina squamata* - 29-Nov	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 29-Jan	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 26-Mar	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 28-May	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 01-Jul	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 13-Aug	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 12-Sep	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina squamata* - 10-Oct	1	5	50.60	-2.30	Dorset (Atlantic Ocean)	Skeletal	see original reference	Haas *et al.*, 1935
Coralline algae	-	*Corallina officinalis*	1	5	49.60	-1.20	Normandy (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Lithothamnium calcareum*	1	10	48.08	-4.00	Atlantic Ocean	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Lithophyllum incrustans*	1	10	48.00	-3.00	English Channel (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Phymatolithon compactum*	1	10	48.00	-55.00	Newfoundland (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Lithophyllum tortuosum*	1	20	44.00	9.00	Genocean acidification (Mediterranean Sea)	Skeletal	see original reference	Lipman & Shelley, 1924
Coralline algae	-	*Lithophyllum proboscideum*	1	15	37.00	-122.00	Monterey Bay (Pacific Ocean)	Skeletal	see original reference	Lipman & Shelley, 1924
Coralline algae	-	*Goniolithon strictum* - old	1	30	25.00	-75.00	Bahamas (Atlantic Ocean)	Skeletal	see original reference	Lipman & Shelley, 1924
Coralline algae	-	*Goniolithon strictum* - old	1	30	25.00	-75.00	Bahamas (Atlantic Ocean)	Skeletal	see original reference	Vaughan, 1918
Coralline algae	-	*Goniolithon strictum* - young	1	30	25.00	-75.00	Bahamas (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Lithophyllum pachydermum*	1	30	25.00	-75.00	Bahamas (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Goniolithon acropectum*	1	20	18.00	-68.00	Puerto Rico (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Amphiroa fragilissima*	1	10	18.00	-68.00	Puerto Rico (Atlantic Ocean)	Skeletal	see original reference	Högbom, 1894
Coralline algae	-	*Lithothamnium nodosum*	1	5	0.00	-90.00	Galapagos Islands (Pacific Ocean)	Skeletal	see original reference	Vinogradov, 1953
Coralline algae	-	*Lithophyllum oncodes*	1	30	-7.00	56.00	Madagascar (Indian Ocean)	Skeletal	see original reference	Lemoine, 1910
Coralline algae	-	*Goniolithon orthoblastum*	1	10	-10.00	145.00	Murray Isle (Pacific Ocean)	Skeletal	see original reference	Lemoine, 1910
Coralline algae	-	*Lithothamnium erubescens*	1	10	-10.00	123.00	Timor (Indian Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Archaeolithothamium episporum*	1	10	-10.00	80.00	Panama (Pacific Ocean)	Skeletal	see original reference	Lemoine, 1910
Coralline algae	-	*Lithothamnium kaiseri*	1	10	-15.00	-172.00	Samocean acidification (Pacific Ocean)	Skeletal	see original reference	Lipman & Shelley, 1924
Coralline algae	-	*Porolithon craspedium*	1	10	-15.00	-172.00	Rose Atoll (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Porolithon oncodes*	1	10	-15.00	-172.00	Samocean acidification (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Amphiroa rigida*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992

Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Coralline algae	-	*Neogoniolithon sp.*	1	5	24.89	-80.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Pulvinulina menardii* - pelagic	1	20	40.56	-66.15	Atlantic Ocean	Shell	see original reference	Clarke & Wheeler, 1922
Foraminifera	-	*Polytrema mineaccum* - benthic	1	100	25.00	-77.00	Bahamas (Atlantic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Foraminifera	-	*Orbitolites marginatis* - benthic	1	50	24.60	-81.96	Florida (Atlantic Ocean)	Shell	see original reference	Brady, 1884
Foraminifera	-	*Amphistegina lessonii* - pelagic	1	20	16.10	-22.95	Cape Verde (Atlantic Ocean)	Shell	see original reference	Brady, 1884
Foraminifera	-	*Sphaeroidina dehiscens* - pelagic	1	20	12.40	121.60	Philippines (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Foraminifera	-	*Orbitolites complanata* - benthic	1	30	-17.30	177.47	Fiji (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	Florida (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	Florida (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	Florida (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Archais sp.*	1	5	24.59	-81.54	Florida (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Globigerinoides ruber*	1	5	11.84	-86.68	Nicaragua (Pacific Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Globigerinoides ruber*	1	5	11.95	-86.68	Nicaragua (Pacific Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Globigerinoides sacculifer*	1	5	11.95	-86.68	Nicaragua (Pacific Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Foraminifera	-	*Globorotalia menardii*	1	5	25.03	-77.83	Bahamas (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Hydrocorallia	-	*Millepora alcicornis*	1	10	24.60	-81.96	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hydrocorallia	-	*Distichopora nitida*	1	20	7.40	151.50	Micronesia (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hydrocorallia	-	*Millepora braziliensis*	1	30	-12.20	-36.80	Brazil (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Madracis decactis*	1	20	32.40	-64.90	Bermuda (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Siderastrea radians*	1	20	32.40	-64.90	Bermuda (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Flabellum alabastrum*	1	10	26.00	-77.20	Bahamas (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Acropora cervicornis*	1	15	26.00	-77.20	Bahamas (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Favia fragum*	1	20	24.60	-81.96	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Dasmosmilia lymani*	1	10	24.60	-81.96	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Balanophyllia floridana*	1	10	24.54	-81.80	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Paracyathus defilipii*	1	10	24.54	-81.80	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Porites lutea*	1	2	24.55	124.33	Off Taiwan (Pacific Ocean)	Skeletal	see original reference	Mitsuguchi *et al.*, 2001
Hexacorallia	-	*Porites sp.*	1	2	-18.28	147.38	East Australia (Pacific Ocean)	Skeletal	see original reference	Mitsuguchi *et al.*, 2001
Hexacorallia	-	*Deltocyathus italicus*	1	20	18.50	-63.51	Caribbean (Atlantic Ocean)		see original reference	Clarke & Wheeler, 1922
Hexacorallia	-	*Desmophyllum ingens*	1	15	-36.55	-73.00	Chile (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Gorgonia sp.*	1	30	54.60	154.40	Sea of Okhotsk (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Alcyonium carneum*	1	50	45.18	-55.85	Newfoundland (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Paramuricea borealis*	1	50	45.18	-55.85	Grand Banks (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Alcyonium carneum*	1	50	45.18	-55.85	Newfoundland (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Pennatula aculeata*	1	50	44.45	-58.51	Banquereau (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922

Octocorallia	-	*Paragorgia arborea*	1	50	44.36	-63.75	Nova Scotia (Atlantic Ocean)	Skeletal	see original reference	Phillips, 1922
Octocorallia	-	*Paragorgia arborea*	1	50	43.00	-62.00	Nova Scotia (Atlantic Ocean)	Skeletal	see original reference	Vinogradov, 1953
Octocorallia	-	*Corallium elatior*	1	40	42.25	130.91	Japan Sea (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Primnoa resedaeformis*	1	30	42.25	130.91	Japan Sea (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Primnoa reseda*	1	40	42.25	-63.25	Nova Scotia (Atlantic Ocean)	Skeletal	see original reference	Velimirov & Böhm, 1976
Octocorallia	-	*Rhipidogorgia flabellum*	1	20	32.40	-64.90	Bermuda (Atlantic Ocean)	Skeletal	see original reference	Velimirov & Böhm, 1976
Octocorallia	-	*Pleurocorallium johnsoni*	1	30	25.75	-20.20	Canary Islands (Atlantic Ocean)	Skeletal	see original reference	Velimirov & Böhm, 1976
Octocorallia	-	*Gorgonia acerosa*	1	50	24.60	-81.96	Florida (Atlantic Ocean)	Skeletal	see original reference	Velimirov & Böhm, 1976
Octocorallia	-	*Leptogorgia pulchra*	1	80	24.60	-108.25	California (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Xiphigorgia anceps*	1	20	24.47	-81.55	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Eunicella singularis*	20	20	42.58	8.75	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Eunicella cavolini*	20	20	42.58	8.75	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Paramuricea clavata*	20	20	42.58	8.75	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Corallium rubrum*	60	60	42.41	8.75	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*E. Barbadensis*	10	10	11.32	-60.7	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Lepidisis spp.*	3945	3945	-45.37	144.57	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Tubipora musica*	5	5	14.21	122.06	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Tubipora musica*	5	5	14.21	122.06	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Tubipora musica*	5	5	14.21	122.06	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Plexaurella grisea*	10	10	11.32	-60.59	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Ellisella barbadensis*	10	10	11.32	-60.59	Tobago (Atlantic Ocean)	Skeletal	see original reference	Esford & Lewis, 1990
Octocorallia	-	*Muricea echinata*	1	10	22.86	-106.10	California (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Leptogorgia rigida*	1	150	22.86	-109.79	California (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Heliopora cerulea*	1	20	12.40	121.60	Philippines (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Tubipora purpurea*	1	10	1.33	103.83	Singapore (Indian Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Phyllogorgia quercifolia*	1	10	-3.83	-32.41	Brazil (Atlantic Ocean)	Skeletal	see original reference	Murray & Renard, 1891
Octocorallia	-	*Ctenocella pectinata*	1	20	-10.00	142.20	Torres Strait (Pacific Ocean)	Skeletal	see original reference	Vinogradov, 1953
Octocorallia	-	*Muricea humilis*	1	30	-12.20	-36.80	Brazil (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Gorgonia subfruticosa*	1	45	-18.00	-178.00	Fiji (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Plexaurella grandiflora*	1	20	-28.40	155.67	Australia (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Eunicella papillose*	1	30	-34.21	18.35	Cape Town (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Eunicella alba*	1	30	-34.22	18.48	False Bay (Indian Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Eunicella tricoronata*	1	30	-34.22	18.48	False Bay (Indian Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Octocorallia	-	*Lophogorgia flamea*	1	30	-34.22	18.48	False Bay (Indian Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Flustra membranacea*	1	50	59.17	-151.60	Alaska (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Cellepora incrassata*	1	50	44.69	-62.69	Grand Banks (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Schizoporella unicornis*	1	10	41.35	-70.79	Vineyard Sound (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Bugula turrita*	1	40	41.23	-70.07	Georges Bank (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Lepralia* sp.	1	20	40.80	14.20	Naples (Mediterranean Sea)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Amathia spiralis*	1	20	35.22	-75.60	Cape Hatteras (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922

Bryozoa	-	*Holoporella albirostris*	1	20	24.47	-81.55	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Bugula neritina*	1	20	24.47	-81.55	Florida (Atlantic Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Microporella grisea*	1	20	-28.40	155.67	Australia (Pacific Ocean)	Skeletal	see original reference	Clarke & Wheeler, 1922
Bryozoa	-	*Adeonellopsis sp.*	1	12	-45.3	166.91	New Zealand (Pacific Ocean)	Skeletal	see original reference	Wejnert &Smith, 2008
Bryozoa	-	*Bugula neritina*	1	5	26.71	-79.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Bryozoa	-	*Bugula neritina*	1	5	26.88	-79.99	Florida (Atlantic Ocean)	Skeletal	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Terebratulina septentrionalis*	1	30	44.87	-66.91	Eastport (Atlantic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Brachiopoda	-	*Laqueus californicus*	1	80	24.60	-108.25	California (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Brachiopoda	-	*Krassina rubra*	1	5	-34.25	18.35	Cape of Good Hope (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Megerlea truncata*	1	5	37.28	13.07	Sicily (Mediterranean Sea)	Shell	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Notosaris sp.*	1	5	-42.94	168.69	New Zealand (Pacific Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Terebratella cruenta*	1	5	-42.84	168.69	New Zealand (Pacific Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Stethothyris sp.*	1	5	-64.03	-61.82	Antarctica	Shell	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Thecidellina sp.*	1	5	12.31	-68.97	Curacao (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Brachiopoda	-	*Thecidellina sp.*	1	5	12.21	-68.97	Curacao (Atlantic Ocean)	Shell	see original reference	Carpenter & Lohmann, 1992
Mollusca	Amphineura	*Mopalia muscosa*	1	120	34.39	-119.70	Santa Barbara (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Bivalvia	*Astarte borealis*	1	50	74.16	54.40	Novaia Zemlya (White Sea)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Bivalvia	*Tellina calcarea*	1	40	74.16	54.33	Novaia Zemlya (White Sea)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Bivalvia	*Pecten groenlandicus*	1	20	73.50	68.83	Barents Sea (Arctic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Bivalvia	*Pecten islandicus*	1	40	71.50	47.00	Barents Sea (Arctic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Bivalvia	*Pecten dislocatus*	1	10	26.81	-82.29	Charlotte Harbor (Atlantic Ocean)	Shell	see original reference	Samoilov & Terentieva, 1925
Mollusca	Bivalvia	*Pecten ventricosus*	1	10	22.86	-106.10	California (Pacific Ocean)	Shell	see original reference	Samoilov & Terentieva, 1925
Mollusca	Bivalvia	*Placuna orbicularis*	1	10	16.83	120.26	Philippines (Pacific Ocean)	Shell	see original reference	Samoilov & Terentieva, 1925
Mollusca	Cephalopoda	*Nautilus pompilius*	1	100	8.53	123.03	Mindanao (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Cephalopoda	*Sepia officinalis*	1	10	5.84	118.27	Philippines (Pacific Ocean)	Shell	see original reference	Terentieva, 1932
Mollusca	Cephalopoda	*Argonauta argo*	1	50	-35.82	175.39	Pacific Ocean	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Gastropoda	*Neptunea despecta*	1	20	69.63	57.35	Barents Sea	Shell	see original reference	Samoilov & Terentieva, 1925
Mollusca	Gastropoda	*Natica clausa*	1	20	60.50	-46.91	Barents Sea	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Gastropoda	*Tachyrhynchus erosa*	1	30	52.90	158.76	Kamchatka (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Gastropoda	*Nassa tegula*	1	20	36.62	-121.91	Monterey Bay (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Gastropoda	*Odontocymbiola magellanica*	1	15	-42.71	-65.02	Chile (Pacific Ocean)	Shell	see original reference	Bigatti *et al.*, 2010
Mollusca	Gastropoda	*Nassa isculpta*	1	50	32.34	-118.43	Cortez Bank (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Mollusca	Scaphopoda	*Dentalium solidum*	1	30	41.23	-70.07	Georges Bank (Atlantic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Crustacea	Cirripedia	*Scalpellum regium*	1	5	52.92	-132.29	Queen Charlotte I (Pacific Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Crustacea	Cirripedia	*Balanus hameri*	1	20	41.23	-70.07	Georges Bank (Atlantic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Crustacea	Cirripedia	*Balanus amphitrite*	1	5	38.92	-74.91	Cape May (Atlantic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Crustacea	Cirripedia	*Lepas anatifera*	1	10	24.47	-81.55	Florida (Atlantic Ocean)	Shell	see original reference	Clarke & Wheeler, 1922
Crustacea	Cirripedia	*Mitella polymerus*	1	10	22.86	-106.10	California (Pacific Ocean)	Shell	see original reference	Samoilov & Terentieva, 1925

Crustacea	Amphipoda	*Tryphosa pinguis*	1	30	41.52	-70.67	Woods Hole (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Isopoda	*Pentidotea wosnesenkii*	1	2	48.75	-125.23	Barnfield (Pacific Ocean)	Carapace	see original reference	Neues *et al.*, 2007
Crustacea	Isopoda	*Sphaeroma serratum*	1	2	45.18	13.68	Slovenia (Mediterranean Sea)	Carapace	see original reference	Neues *et al.*, 2007
Crustacea	Isopoda	*Gnovimosphaeroma oregonensis*	1	2	48.75	-125.23	Barnfield (Pacific Ocean)	Carapace	see original reference	Neues *et al.*, 2007
Crustacea	Decapoda	*Crago dalli*	1	40	59.17	-151.60	Alaska (Pacific Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Pagurus rathbuni*	1	210	58.46	-175.22	Bering Sea (Arctic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Homarus americanus* - small	1	30	43.84	-69.64	Boothbay Harbor (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Homarus americanus* - medium	1	30	43.84	-69.64	Boothbay Harbor (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Homarus americanus* - large	1	30	43.84	-69.64	Boothbay Harbor (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Homarus americanus*	1	50	41.35	-70.79	Vineyard Sounds (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Libinia emarginata*	1	20	41.35	-70.79	Vineyard Sounds (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Munida iris*	1	20	37.62	-76.26	Chesapeake Bay (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Pandalus platyceros*	1	50	36.62	-121.91	Monterey Bay (Pacific Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Palinurus argus*	1	60	21.84	-71.33	West Indies (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Decapoda	*Grapsus grapsus*	1	60	-9.36	46.40	Aldabra Island (Indian Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922
Crustacea	Stomatopoda	*Chloridella empusa*	1	20	24.47	-81.55	Florida (Atlantic Ocean)	Carapace	see original reference	Clarke & Wheeler, 1922

Table S4. Quality control data for the main elements analyzed via ICP-MS, including Mg and Ca.

Analyte Symbol	Li	Be	B	Na	Mg	Al	K	Bi	Ca
Unit Symbol	ppm	ppm	ppm	%	%	%	%	ppm	%
Detection Limit	0.1	0.1	1	0.001	0.01	0.01	0.01	0.02	0.01
Analysis Method	AR-MS	AR-MS	AR-MS	AR-MS	AR-MS	AR-MS	AR-MS	AR-MS	AR-MS
GXR-1 Meas	5.9	1.2	16	0.045	0.14	0.32	0.04	1450	0.79
GXR-1 Cert	8.2	1.22	15	0.052	0.217	3.52	0.05	1380	0.96
GXR-4 Meas	11.9	2	5	0.131	1.67	2.71	2.06	19.8	0.84
GXR-4 Cert	11.1	1.9	4.5	0.564	1.66	7.2	4.01	19	1.01
GXR-2 Meas	52	1.4	19	0.124	0.41	2.8	0.73	0.27	0.65
GXR-2 Cert	54	1.7	42	0.556	0.85	16.5	1.37	0.69	0.93
GXR-6 Meas	25.1	0.9	4	0.075	0.34	5.93	1.14	0.16	0.18
GXR-6 Cert	32	1.4	9.8	0.104	0.609	17.7	1.87	0.29	0.18
OREAS 13P Meas									
OREAS 13P Cert									
Method Blank				<	<	<	<	<	<
Method Blank	< 0.1	< 0.1	< 1	0.001	0.01	0.01	0.01	0.02	0.01

Table S5. Details of the field photos and metadata used in Fig. 3. Grey cells indicate in situ data recovered in the field survey and not from the NEAR3D analysis. TO CHANGE IN MANUSCRIPT CITATION

	Metadata							
Photo Tag	Class	Species	Depth (m)	Lat.	Long.	Ocean	Collection	Source
# Ophi. 4	Echinodermata	Ophiuroidea	*Ophiothrix fragilis*	40.000	60.534	1.232	Atlantic	Commercial ROV
# Ophi. 10	Echinodermata	Ophiuroidea	*Ophiosparta* sp.	732.000	-66.914	-72.574	Southern	Towed camera
# Ophi. 16	Echinodermata	Ophiuroidea	Indetermined white-yellow ophiuroid	2580.000	-9.380	40.720	Indian	Commercial ROV
# Ophi. 15	Echinodermata	Ophiuroidea	Indetermined white-pink ophiuroid	4100.000	34.830	-123.000	Pacific	Sled camera
# Ast. 14	Echinodermata	Asteroidea	*Asterias rubens*	184.000	60.187	-3.839	Atlantic	Commercial ROV
# Ast. 9	Echinodermata	Asteroidea	Indetermined red asteroid	722.000	-66.914	-72.574	Southern	Towed camera
# Ast. 3	Echinodermata	Asteroidea	*Hyphalaster inermis*	5440.000	31.283	-25.400	Atlantic	Bathysnap camera
# Echi. 2	Echinodermata	Echinoidea	*Diadema* sp.	106.800	5.028	4.466	Atlantic	ROV video
# Echi. 4	Echinodermata	Echinoidea	*Phormosoma* sp.	772.100	5.001	-4.532	Atlantic	ROV video
# Echi. 8	Echinodermata	Echinoidea	Indetermined pink regular echinoid	2264.000	-66.872	-72.678	Southern	Towed camera
# Echi. 12	Echinodermata	Echinoidea	Indetermined pink regular echinoid	4100.000	34.830	-123.000	Pacific	Sled camera
# Holoth. 8	Echinodermata	Holothuroidea	*Stichopus tremulus*	357.000	72.100	22.770	Atlantic	Commercial ROV
# Holoth. 2	Echinodermata	Holothuroidea	*Pelopatides mammillatus*	3305.000	23.504	59.498	Indian	Towed camera
# Crin. 6	Echinodermata	Crinoidea	Indetermined white crinoid	184.000	60.280	-4.830	Atlantic	Commercial ROV
# Crin. 4	Echinodermata	Crinoidea	*Poliometra prolixa*	1080.000	60.562	-4.456	Atlantic	Commercial ROV
# Crin. 1	Echinodermata	Crinoidea	*Anachalypsicrinus nefertiti*	2619.000	48.735	-28.655	Atlantic	ISIS ROV
# Crin. 5	Echinodermata	Crinoidea	Indetermined white-yellow crinoid	4100.000	34.830	-123.000	Pacific	Sled camera
# Crust. 2	Crustacea	Decapoda	*Galathea* sp.	330.100	5.032	4.468	Atlantic	ROV video
# Crust. 1	Crustacea	Decapoda	Majidae	615.600	5.001	-4.532	Atlantic	ROV video
# Crust. 11	Crustacea	Decapoda	*Parapagurus pilosimanus*	1159.000	-10.620	40.840	Indian	Commercial ROV
# Crust. 8	Crustacea	Cirripedia	*Alcockianum alcockianum*	2580.000	-9.380	40.720	Indian	Commercial ROV
# Crust. 4	Crustacea	Decapoda	*Lithodidae* sp.	2619.000	48.735	-28.655	Atlantic	ISIS ROV
# Crust. 9	Crustacea	Decapoda	*Geryon trespinosus*	3000.000	20.200	68.810	Indian	Commercial ROV
# Crust. 6	Crustacea	Cirripedia	Indetermined white cirriped	4100.000	34.830	-123.000	Pacific	Sled camera
# Cnida. 1	Cnidaria	Anthozocean acidification	*Gersemia* sp	1080.000	60.562	-4.456	Atlantic	Commercial ROV
# Cnida. 2	Cnidaria	Anthozocean acidification	Octocorallia	4100.000	34.830	-123.000	Pacific	Sled camera

	NEAR3D analysis					Mg-calcite			Calculations			
Photo Tag	T	S	CO_3^{2-}	pH_{total}	pCO_2	mol $MgCO_3$%	Mg/Ca	Original Mg-calcite	$\Omega_{Cal.}$	$\Omega_{Arag.}$	$\Omega_{Mg\text{-}x}$ (cleaned)	$\Omega_{Mg\text{-}x}$ (min. prep)
# Ophi. 4	8.804	35.122	135.948	8.066	375.113	13.571	0.159	*Ophiothrix angulata*	3.275	2.184	2.717	0.954
# Ophi. 10	0.980	34.718	80.456	7.892	464.770	10.738	0.120	*Ophionotus victoriae*	1.745	1.174	1.677	0.891
# Ophi. 16	2.100	35.100	83.390	7.858	484.891	9.577	0.138	*Ophiosium lynami*	1.263	0.869	1.267	0.794
# Ophi. 15	1.500	34.600	74.261	7.767	514.592	9.577	0.138	*Ophiosium lynami*	0.831	0.582	0.835	0.523
# Ast. 14	3.053	34.469	123.188	8.127	311.254	4.807	0.134	*Asterias rubens*	2.924	1.954	3.384	3.568
# Ast. 9	0.970	34.716	80.814	7.882	458.721	11.506	0.130	*Labidiaster annulatus*	1.757	1.181	1.639	0.778
# Ast. 3	2.157	34.858	98.695	7.857	336.498	8.331	0.148	*Zorocean acidificationster fulgens*	0.873	0.622	0.918	0.678
# Echi. 2	15.534	35.594	125.205	7.896	595.334	6.905	0.088	*Cidaris blakei*	2.969	1.982	2.891	2.520
# Echi. 4	5.403	34.585	70.768	7.793	690.945	8.770	0.136	*Tripneustes ventricosus*	1.483	0.998	1.514	1.056
# Echi. 8	1.110	34.702	77.273	7.866	476.218	8.908	0.098	*Ctenocidaris perrieri*	1.232	0.844	1.271	0.871
# Echi. 12	1.500	34.600	74.261	7.767	514.592	6.359	0.072	*Echinus affinis*	0.831	0.582	0.934	0.861
# Holoth. 8	-0.012	34.875	108.266	8.109	312.022	8.770	0.096	*Pseudostichopus spiculiferus*	2.567	1.719	2.663	1.858
# Holoth. 2	1.822	34.741	77.047	7.787	542.985	8.770	0.096	*Pseudostichopus spiculiferus*	1.006	0.698	1.041	0.727
# Crin. 6	3.053	34.469	123.188	8.127	311.254	13.582	0.157	*Isocrinus decorus*	2.924	1.954	2.518	0.883
# Crin. 4	-0.702	35.199	105.495	8.092	310.836	11.826	0.138	*Pentametrocrinus japonicus*	2.183	1.474	2.014	0.912
# Crin. 1	3.300	34.950	110.396	7.982	333.362	13.502	0.157	*Endoxocrinus parra*	1.652	1.137	1.426	0.505
# Crin. 5	1.500	34.600	67.438	7.715	583.636	13.502	0.157	*Endoxocrinus parra*	0.755	0.528	0.654	0.232
# Crust. 2	10.157	34.710	52.839	7.586	1222.203	9.381	0.120	*Homarus americanus*	1.188	0.795	1.137	0.732
# Crust. 1	6.252	34.575	47.843	7.596	1134.484	9.462	0.158	*Pandalus platyceros*	1.030	0.691	1.018	0.647
# Crust. 11	5.179	34.757	76.312	7.813	641.975	6.812	0.088	*Pagurus rathbuni*	1.494	1.010	1.635	1.439
# Crust. 8	2.100	35.100	83.390	7.858	484.891	2.637	0.027	*Scalpellum regium*	1.263	0.869	1.459	1.733
# Crust. 4	3.300	34.950	110.396	7.982	333.362	10.106	0.134	*Libinia emarginata*	1.652	1.137	1.618	0.941
# Crust. 9	1.715	34.742	76.957	7.796	541.337	7.253	0.101	*Grapsus grapsus*	1.065	0.736	1.164	0.977
# Crust. 6	1.500	34.600	74.261	7.767	514.592	10.175	0.125	*Munida iris*	0.856	0.611	0.820	0.511
# Cnida. 1	-0.702	35.199	107.461	7.998	391.804	10.841	0.124	*Gorgonia sp.*	2.224	1.502	2.129	1.114
# Cnida. 2	1.500	34.600	74.261	7.767	514.592	14.660	0.180	*Rhipidogorgia flabellum*	0.831	0.582	0.692	0.209