remote sensing

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Data Descriptor

coastTrain: A Global Reference Library for Coastal Ecosystems

Nicholas J. Murray [1,*], Pete Bunting [2], Robert F. Canto [1], Lammert Hilarides [3], Emma V. Kennedy [4], Richard M. Lucas [2], Mitchell B. Lyons [5,6], Alejandro Navarro [1], Chris M. Roelfsema [6], Ake Rosenqvist [7], Mark D. Spalding [8,9], Maren Toor [1] and Thomas A. Worthington [9]

1 College of Science and Engineering, James Cook University, Townsville, QLD 4811, Australia
2 Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth SY23 3DB, UK
3 Wetlands International, 6700 AL Wageningen, The Netherlands
4 Australian Institute of Marine Science, Townsville, QLD 4072, Australia
5 Centre for Ecosystem Science, University of New South Wales, Sydney, NSW 2052, Australia
6 Remote Sensing Research Centre, School of Earth and Environmental Sciences, University of Queensland, Brisbane, QLD 4072, Australia
7 solo Earth Observation (soloEO), Tokyo 104-0054, Japan
8 The Nature Conservancy, 53100 Siena, Italy
9 Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge CB2 3QZ, UK
* Correspondence: nicholas.murray@jcu.edu.au

Abstract: Estimating the distribution, extent and change of coastal ecosystems is essential for monitoring global change. However, spatial models developed to estimate the distribution of land cover types require accurate and up-to-date reference data to support model development, model training and data validations. Owing to the labor-intensive tasks required to develop reference datasets, often requiring intensive campaigns of image interpretation and/or field work, the availability of sufficiently large quality and well distributed reference datasets has emerged as a major bottleneck hindering advances in the field of continental to global-scale ecosystem mapping. To enhance our ability to model coastal ecosystem distributions globally, we developed a global reference dataset of 193,105 occurrence records of seven coastal ecosystem types—muddy shorelines, mangroves, coral reefs, coastal saltmarshes, seagrass meadows, rocky shoreline, and kelp forests—suitable for supporting current and next-generation remote sensing classification models. *coastTrain* version 1.0 contains curated occurrence records collected by several global mapping initiatives, including the Allen Coral Atlas, Global Tidal Flats, Global Mangrove Watch and Global Tidal Wetlands Change. To facilitate use and support consistency across studies, *coastTrain* has been harmonized to the International Union for the Conservation of Nature's (IUCN) Global Ecosystem Typology. *coastTrain* is an ongoing collaborative initiative designed to support sharing of reference data for coastal ecosystems, and is expected to support novel global mapping initiatives, promote validations of independently developed data products and to enable improved monitoring of rapidly changing coastal environments worldwide.

Keywords: mangroves; tidal flats; mudflats; tidal marshes; tidal wetlands; training set; machine learning; occurrence records; deep learning; feature set

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1. Summary

Mapping the distribution and change of the world's coastal ecosystems is essential to monitoring their status, and to support policy and management interventions for their protection or sustainable utilization [1–5]. Yet, despite significant recent advances in cloud-based geospatial analysis platforms and improved access to Earth observation archives, global-scale monitoring of many coastal ecosystem types has remained unfeasible [4,5]. This is partly due to the considerable resources required to develop large, analysis-ready, reference datasets suitable for training and validating remote sensing classification models and algorithms for biophysical retrieval or classification [6,7]. Reference data are often developed through field work [7–9], image interpretation [7,10,11], or by sampling previously developed maps [12–14]. However, these approaches are highly labor-intensive and, in the case of sampling existing maps, can propagate uncertainties among otherwise independent mapping programs [11].

Compiling data from multiple contributors in open-access curated databases is one approach that could address the training data bottleneck that is hindering an improved understanding of the distribution of change of ecosystems at the global scale. For example, initiatives such as the international TRY plant trait database, which hosts more than 11 million contributed records under an open access data policy, have been instrumental in enabling advances in plant trait-based research and documenting major knowledge gaps [15,16]. Similar efforts to support global scale remote sensing models are essential because conservation targets increasingly require detailed estimates of global ecosystem distributions.

Here we introduce *coastTrain*, a database of occurrence records of seven coastal ecosystem types (muddy shorelines, mangroves, coral reefs, coastal saltmarshes, seagrass meadows, rocky shoreline, and kelp forests) designed to support distribution models developed from global scale, high-resolution data sources. *coastTrain* draws together training data from four major global coastal ecosystem mapping efforts and contains 193,105 occurrence records spatially distributed around the world's coastline with data from every continent (except Antarctica), ocean and major seas, and including coastal areas of more than 120 countries (Figure 1). To assemble the *coastTrain* database (version 1.0), we developed a data curation pipeline that enabled the compilation of independently developed training sets, standardisation to a common classification scheme, an internal review process and the delivery of versioned releases to end-users (Figure 2). Data included in *coastTrain* are collated from the following projects: Allen Coral Atlas (https://allencoralatlas.org, accessed on 15 September 2022), Global Tidal Flats (https://intertidal.app, accessed on 15 September 2022), Global Mangrove Watch (https://www.globalmangrovewatch.org, accessed on 15 September 2022) and the Global Tidal Wetlands Change (www.globalintertidalchange.org, accessed on 15 September 2022) project. By developing a globally distributed, analysis-ready validated reference library of coastal ecosystems, *coastTrain* is among the first publicly accessible datasets suitable to underpin current and next-generation models of the distribution of these ecosystems.

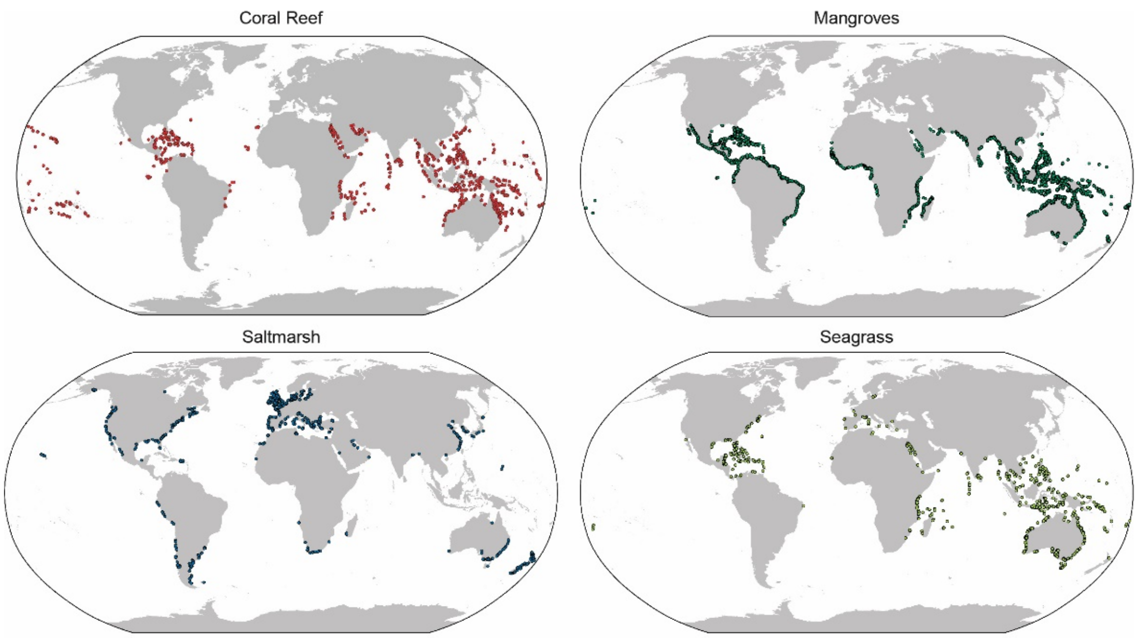

Figure 1. *Cont.*

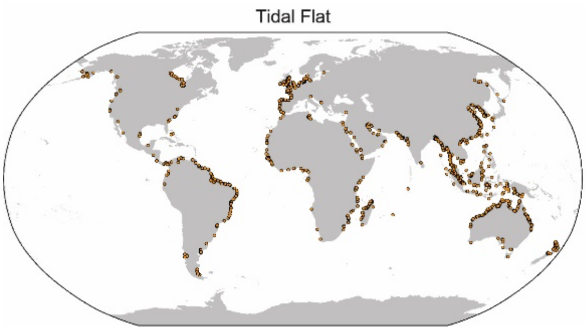

Figure 1. The global distribution of the five major coastal ecosystem occurrence records included in the *coastTrain* training library. Records for other cover types ('permanent water' and 'terrestrial other'; n = 13,260) are not shown on this figure. Records for ecosystems that are still under development and are likely to be considerably expanded in future versions, including kelp forests (n = 12 records) and rocky shores (n = 56 records), are not shown. Note the majority of mapping programs did not collect occurrence records above 60°N.

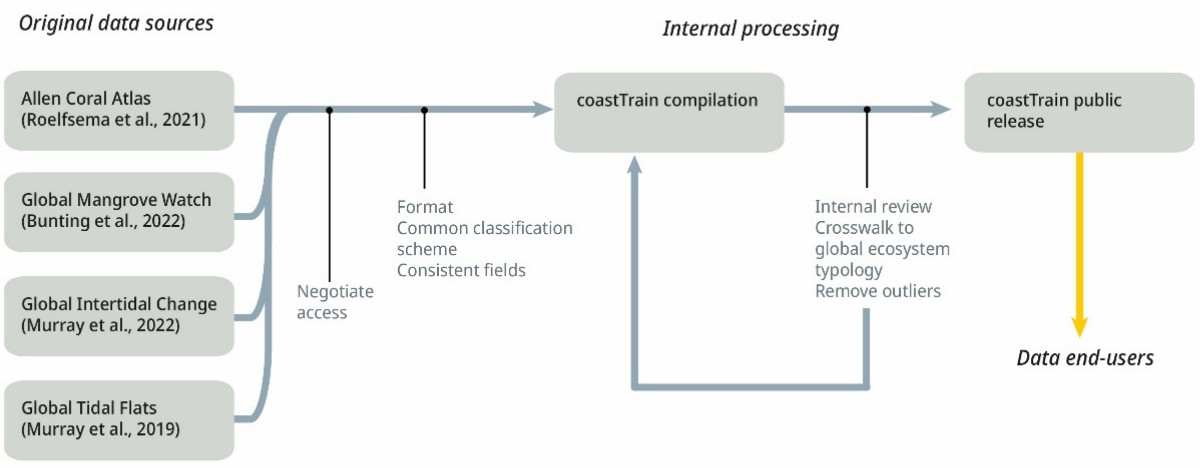

Figure 2. The data curation pipeline used to assemble *coastTrain* from four global-scale coastal ecosystem mapping initiatives (left). A subset or all of the training data is submitted to the *coastTrain* processing pipeline, formatted to a common data format with consistent classification scheme and compiled into a version of the database. A data validation and cross-walking sub-component is applied, and a versioned release is made available to users via an open-access data repository [7,10–12].

2. Data Description

2.1. Overview

coastTrain is a standalone reference dataset developed to allow for rapid development, deployment and validation of global-scale maps of coastal ecosystem distributions (Figure 1). Primarily, *coastTrain* was developed to reduce the cost of setting up and running different formulations of satellite image-based coastal ecosystem classification models. In addition, *coastTrain* was made openly accessible with the aspiration to spark new efforts by research communities worldwide to improve the documentation of the distribution and change of the world's coastal ecosystems. We brought together a project team consisting of project leaders of several of the world's major coastal ecosystem mapping initiatives, forming an initial active collaboration to promote the open-sharing of reference data. With open data contributions by the Allen Coral Atlas [7,17–19], Global Mangrove Watch [12,13,20,21], Global Tidal Wetlands Change [11] and the Global Tidal Flats [10,22,23] research programs, we hope to support other ongoing and novel mapping and monitoring initiatives for coastal ecosystems while encouraging sharing of additional important coastal ecosystem reference datasets.

coastTrain Version 1.0 includes point-format occurrence records with data fields that describe the project source and acquisition method, the appropriate scale of use and reference periods for applicable use of each record. In addition, each data record has fields to cross-walk the coastal ecosystem type to the most appropriate Ecosystem Functional Group identified by the International Union for the Conservation of Nature (IUCN) Global Ecosystem Typology. This is a newly developed framework for categorizing the Earth's ecosystems according to their ecosystem functions, ecological processes, structural features and characteristic biota [4,5,24]. Importantly, cross-referencing the reference data in *coastTrain* with the Global Ecosystem Typology offers two-way benefits, including (*i*) a detailed class definition for each occurrence record, and (*ii*) a curated set of occurrence records that can support future collaborative efforts to map all of the ecosystem functional groups identified by the global ecosystem typology [5].

2.2. Class Definitions

The primary sources for detailed class definitions of the occurrence records in *coastTrain* were the peer-reviewed publications arising from each project. However, to promote consistent and rapid use of *coastTrain* across a wide-variety of use-cases, we cross-walked all data records to the newly developed IUCN Global Ecosystem Typology [5,24]. The Global Ecosystem Typology is a global standard for the consistent classification of the world's ecosystems, and includes detailed ecosystem descriptions developed by experts. The descriptions describe ecosystem properties, key ecological drivers, information about characteristic native biota and the typical biophysical habitat of each ecosystem type. Each description is accompanied by a conceptual model that indicates links between ecological traits, drivers and ecosystem properties. Although ecosystem class definitions inevitably vary between different mapping and classification initiatives due to issues such as variability in expert opinion, efforts to cross-walk these classifications are vital to support emerging efforts to develop consistent global maps of ecosystems from a variety of information sources [1,4,5].

Ecosystem Functional Groups from the IUCN Global Ecosystem Typology that were cross-walked to the *coastTrain* database are muddy shorelines [25], intertidal forests and shrublands [26], photic coral reefs [27], coastal saltmarshes and reedbeds [28], seagrass meadows [29], rocky shorelines [30] and kelp forests [31]. These correspond to *coastTrain* occurrence records for tidal flat, mangrove, coral reef, salt-marsh/tidal marsh and seagrass (Table 1). Each contributor to *coastTrain* used the published ecosystem descriptions, conceptual models and considerable theoretical background provided by the IUCN Global Ecosystem Typology (www.global-ecosystems.org, accessed on 15 September 2022) to ensure the cross-walked Ecosystem Functional Groups were appropriate for their data.

Table 1. Coastal ecosystem types included in the *coastTrain* dataset. Realm, biome and ecosystem functional group correspond to the IUCN Global Ecosystem Typology [5]. Although rocky shorelines and kelp forests are poorly represented in *coastTrain v1.0*, we expect the number of records to grow with new submissions and expansions mapping programs over time.

Ecosystem Type	Class Value	Realm	Biome	Ecosystem Functional Group	No. Records
Tidal flat	2	Marine-Terrestrial	Shorelines	Muddy shorelines	4695
Mangrove	3	Marine-Freshwater-Terrestrial	Brackish tidal	Intertidal forests and shrublands	112,600
Coral reef	4	Marine	Marine shelf	Photic coral reefs	51,962
Saltmarsh/tidal marsh	5	Marine-Freshwater-Terrestrial	Brackish tidal	Coastal saltmarshes and reedbeds	5851
Seagrass	6	Marine	Marine shelf	Seagrass meadows	4669
Rocky intertidal	9	Marine-Terrestrial	Shorelines	Rocky shorelines	56
Kelp forest	10	Marine	Marine shelf	Kelp forests	12

3. Method

coastTrain was developed by compiling training and validation data already used in four major global coastal ecosystem mapping initiatives (Figure 2). To help balance the number of training samples generated within each project, we provided an option for these projects to submit either a random subset (Allen Coral Atlas or Global Mangrove Watch) or the full training data set (Global Tidal Flats and Global Tidal Wetland Change).

3.1. Source Data

3.1.1. Allen Coral Atlas

The Allen Coral Atlas [32] is a global mapping initiative that developed geomorphic and benthic maps of the world's shallow tropical coral reefs using Planet Dove satellite imagery, physical attributes and reference data. The first stage of the Allen Coral Atlas mapping pipeline uses a random forest classifier to create geomorphic zonation and benthic cover type maps, which were trained using a large, globally distributed training dataset (>1,500,000 records) collected between the 30 degrees North and South. Points in the training data set were sampled from a reference dataset of image segments. The segments were generated from object-based image analysis (OBIA) of high resolution satellite image data (5m Planet DOVE), which were then allocated one of 12 geomorphic classes and one of six benthic classes in the *ReefCover* classification scheme [19]. Classes were assigned with visual reference to the high resolution satellite imagery, aided and supplemented by cross reference to other available data (transect, survey, map) and interpretation cues. Roelfsema, et al. [7] provides detailed information about the methods used to develop the reference data whilst Kennedy, et al. [19] defines the map classes used in the Allen Coral Atlas, and the full Allen Coral Atlas data is available on the figshare archive [33].

To incorporate Allen Coral Atlas data into the *coastTrain* dataset, we filtered the full training dataset of annotated segments for two out of the six benthic type for records corresponding to 'seagrass' and 'coral/algae' [see 19 for full Allen Coral Atlas class definitions] as it describes bottom type, unlike the geomorphic zonation. We randomly sampled segments from the full global set and from within each segment selected 53,942 single pixels at random for inclusion into the *coastTrain* dataset. The final Allen Coral Atlas submission consisted of 1980 seagrass records and 51,962 coral reef records.

3.1.2. Global Tidal Flats

The Global Tidal flats project (https://intertidal.app, accessed on 15 September 2022) aimed to provide the first high-resolution global scale maps of the distribution and change of tidal flat ecosystems [10]. This project defined tidal flats as several types of tidal flat ecosystems, including unconsolidated fine-grain sediments (tidal mudflats), unconsolidated coarse-grain sediments (tidal sand flats) and consolidated sediments, organic material or rocks (wide tidal rock-platforms) [10]. After initial work that included tide models [34,35] and historical map archives [36,37], the global tidal flats project developed a machine-learning classification approach that used covariates developed from nearly 700,000 Landsat Archive images [10]. The classification model was trained from 10,701 records representing the occurrence of tidal flats, as well as two non-tidal flat classes ('permanent water' and 'terrestrial other'). The training data were primarily developed through image interpretation, where analysts were offered a range of image sources and visualisations to systematically interpret the distribution of tidal flat ecosystems around the world's coastline [10,11]. In general, pixels were only included in the training set when they were evaluated as consisting wholly of a single ecosystem type. Analysts also used field experience, published studies and other information sources to aid the interpretation task. The data submission from the Global Tidal Flats project included 7147 records of tidal flats, permanent water and terrestrial other (Table 2).

3.1.3. Global Tidal Wetlands Change

The Global Tidal Wetlands Change project sought to address the problem of significant uncertainty about coastal ecosystem dynamics introduced through modelling highly connected intertidal ecosystems in isolation [11]. The classification workflow classifies the type, timing and change of tidal wetlands and their component ecosystems globally [11]. The Global Tidal Wetlands Change classification models were trained from 32,016 occurrence records of tidal marshes, tidal flats (including all data from the Global Tidal Flats project), and mangroves developed using the same generalised image-interpretation workflow developed in the Global Tidal Flats project [10], and two non-tidal flat classes ('permanent water' and 'terrestrial other'). *coastTrain* Version 1.0 includes the full set of training data [38] developed to map the distribution and change of tidal wetlands, including several classes used to distinguish the tidal wetland classes (tidal marsh, tidal flat and mangrove types) from alternative land uses (Table 2).

3.1.4. Global Mangrove Watch

The Global Mangrove Watch (www.globalmangrovewatch.org, accessed on 15 September 2022) is a mapping program that provides open-access geospatial data about the extent and change of mangroves at the global scale [12,13,21]. The principal publicly available data product from the Global Mangrove Watch is a set of time-series of global maps depicting the changing extent of mangroves for 11 annual epochs between 1996 and 2020 [20]. The mangrove baseline for 2010 (version v2.5) was developed by analyzing Landsat and Sentinel-2 optical sensors and ALOS PALSAR radar satellite data, with reference to more than 4 million mangrove data records. The reference data records were initially derived from a random sample of pixels from the intersecting regions of the Giri, et al. [39] and Spalding [40] mangrove extent maps, spatially stratified across 128 localities across all known mangrove regions [12,13,21]. The automatically generated reference records were validated visually against reference imagery, and samples were manually added for regions where records were missing. For inclusion in *coastTrain* Version 1.0, we randomly sampled 100,000 reference points from the full Global Mangrove Watch reference library.

Table 2. The number of occurrence records in the *coastTrain* dataset.

Project	Project Description	Ecosystem Types	Number of Records	References
Allen Coral Atlas	Developed the first global map of shallow water tropical reefs using Planet satellite imagery and derived products.	Coral reef, Seagrass	51,962 1980	Allen Coral Atlas [32] Kennedy, et al. [19] Lyons, et al. [17] Roelfsema, et al. [7] Roelfsema, et al. [33]
Global Tidal Flats	Developed the first global maps of tidal flats for 11 time periods over the period 1984–2016 using Landsat Archive data.	Tidal flat Terrestrial other Permanent water	1973 2658 2516	Murray, et al. [10] Murray, et al. [23]
Global Tidal Wetland Change	Maps the global extent and the type and timing of change of tidal wetlands (tidal, flats, tidal marshes, mangroves) from 1999 to 2019 using Landsat Archive data.	Tidal flat Saltmarsh Mangrove Seagrass Rocky intertidal Kelp forest Terrestrial other Permanent water	2722 5851 12,600 2689 56 12 6338 1748	Murray, et al. [11] Murray, et al. [38]

Table 2. *Cont.*

Project	Project Description	Ecosystem Types	Number of Records	References
Global Mangrove Watch	Provides open access geospatial data on the extent and change of mangroves from an analysis of JAXA L-band SAR (JERS-1, ALOS PALSAR and ALOS-2 PALSAR-2) data for 11 annual epochs between 1996 and 2020.	Mangrove	100,000	Bunting, et al. [12] Bunting, et al. [13] Bunting, et al. [21]
Total records			193,105	

3.2. Data Harmonization

To harmonize each source record into the *coastTrain* format we developed a processing workflow that included a series of operations to generate unique record identifiers, apply the *coastTrain* class codes, add fields corresponding to the IUCN Ecosystem Typology and acknowledge the source project (Table 3). These data processing operations were completed in Google Earth Engine and QGIS, and enabled the production of a consistent dataset where each record has a complete set of attributes suitable for data filtering and modelling operations.

Table 3. Structure of the attribute table for each record in the *coastTrain* dataset.

Field	Description	Example Value
Type	The geospatial feature type, typically a feature.	feature
ID	Unique identifier for each individual record	1
Lat	Latitude	37.607
Lon	Longitude	−122.114
Class	Categorical variable of an integer representing ecosystem type of the record following the *coastTrain* classification scheme (Table 2).	2
Method	Principal method of data acquisition in the primary source project.	Image interpretation
Scale	Reference scale and indicator of appropriate spatial scale for use.	30
IUCN_Realm	One of five major components of the biosphere as described in the IUCN Global Ecosystem Typology [5,24].	Marine-Terrestrial
IUCN_Biome	A component of a realm united by broad features of ecosystem structure and one or a few major ecological drivers as described in the IUCN Global Ecosystem Typology [5,24].	Shorelines
IUCN_Funct	A group of related ecosystems within a biome that share common ecological drivers, as described in the IUCN Global Ecosystem Typology [5,24].	Muddy Shorelines
IUCN_FunGC	The IUCN Ecosystem Typology Ecosystem Functional Group Code [5,24].	MT1.2
RefDatSta	The beginning of the time period for which the occurrence record has either been confirmed against reference imagery or as indicated as applicable by the source project.	2014
RefDatEnd	The end of the time period for which the occurrence record has either been confirmed against reference imagery or as indicated as applicable by the source project.	2016
Proj_Ref	A code to reference the source mapping project that submitted the data.	GIC
Ecosys_Typ	Generic descriptor of coastal ecosystem type (e.g., mangrove, tidal flat . . .)	Tidal Flat

3.3. Validation

We quality assured the *coastTrain* dataset in four ways. First, we accepted data from programs that had a record of peer-reviewed publications derived from their training data. Second, we worked closely with the principal investigators of each source project to ensure that data submitted to *coastTrain* meets a stated quality aspiration of analysis-ready data. Third, we plotted the elevation of each data record against all other values in *coastTrain* for the same ecosystem to identify and remove any outlying records (i.e., outside the expected elevation range; Figure 3). Lastly, we established a feedback mechanism and website whereby end users are encouraged to flag any records requiring correction by submitting the unique identifier to be fixed in future versions of *coastTrain*.

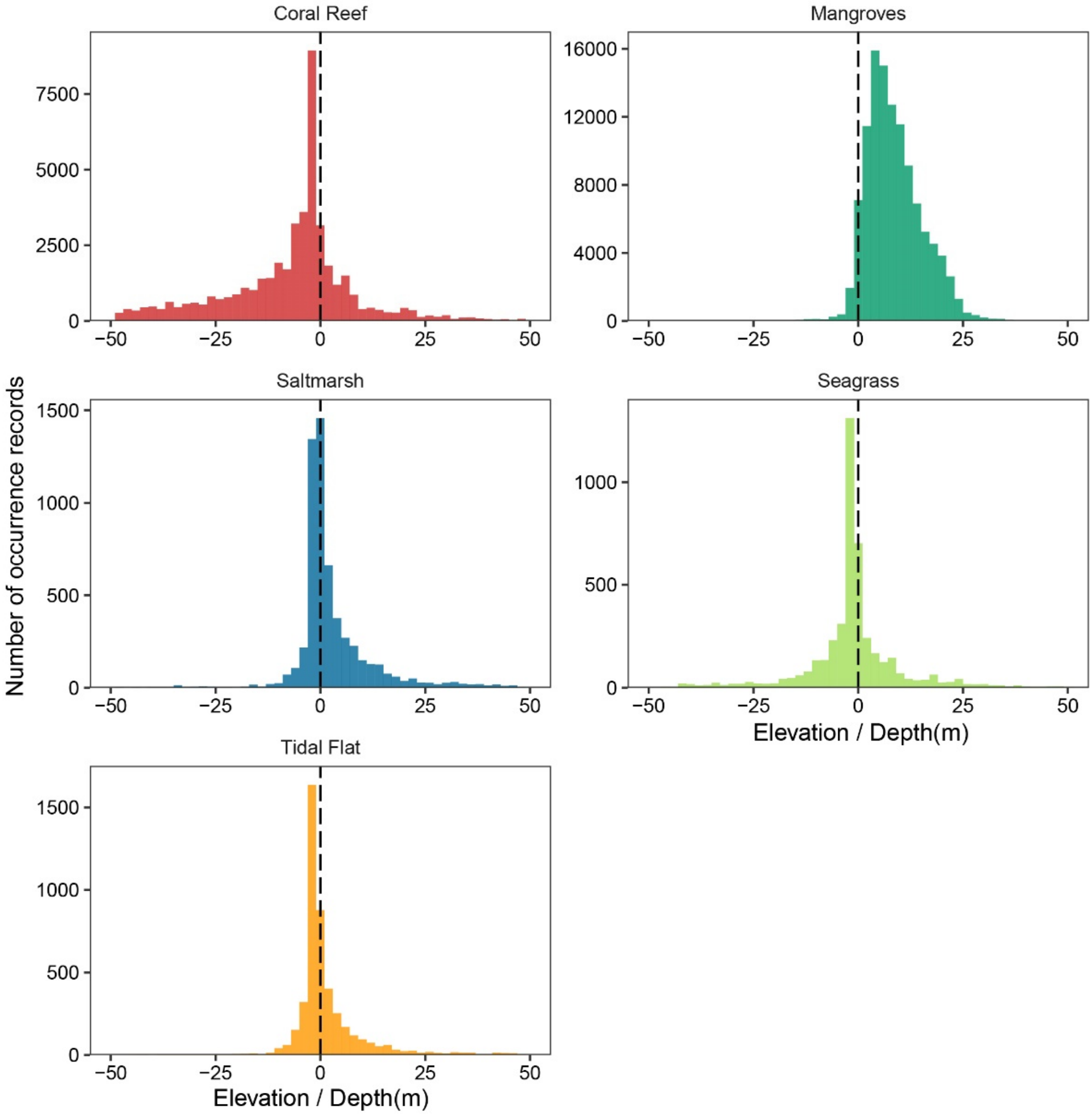

Figure 3. Elevation and depth summaries of each class in the *coastTrain* dataset. Each *coastTrain* data record was intersected with the ETOPO global relief dataset [41] to obtain their mapped elevation and depth with reference to sea level (0 m). Histograms for poorly represented coastal ecosystems (rocky shores and kelp forests) or for the 'permanent water' and 'terrestrial other' classes are not presented in this figure. Note that ETOPO integrates regional and global datasets into a global relief model developed at 1 arc-minute resolution.

4. User Notes

coastTrain is version controlled via GitHub with versioned releases delivered via Zenodo (see Data Availability Statement). It is available as a GeoJSON file suitable for use in widely used geographic information systems (e.g., QGIS), programming platforms (e.g., *R*, *Python*) and cloud-based geospatial analysis platforms (e.g., Google Earth Engine). An interactive website displaying the current version of *coastTrain* is provided at www.coasttrain.org, accessed on 15 September 2022.

Usage Notes

The *coastTrain* dataset was developed to support a range of potential uses, such as training classification models and validating independently developed ecosystem distribution models. However, there are several issues that users should be aware of when using *coastTrain*, including:

1. Point-occurrence training sets support a wide variety of spatial models. However, we recommend users visualize data records and familiarize themselves with the features that each point represents.
2. Although *coastTrain* occurrence records are globally distributed (Figure 1), the aims of each source project may have limited their collection in certain ways. For example, no saltmarsh or tidal flat records are above 60°N or 60°S due to limitations of the two global intertidal change models. Therefore, we recommend all users of *coastTrain* become very familiar with each of the source projects, with detailed information available via their peer-reviewed publications, data records and spatial metadata.
3. Although we do not explicitly state any limits to the use of *coastTrain*, use cases well outside of the stated aim of supporting the spatial modelling of coastal ecosystem types may lead to poor outcomes.
4. Coastal ecosystems are highly dynamic, and any use of *coastTrain* should utilise the RefDatSta and RefDatEnd to avoid sampling coastal ecosystems in locations of extreme change.
5. As a data compilation, data records in *coastTrain* do not follow any standardized sampling strategy. Users should refer to source project documentation to understand the sample design and methods of data collected in the *coastTrain* database.

5. Conclusions

We envision *coastTrain* as a continually updated open-source reference library that is freely available, well documented, analysis ready and version controlled, and which—due to its utility to a large research community—will continue to grow in both records and contributors over time. We see *coastTrain* supporting a broad suite of current and next-generation models, by focusing future work on the inclusion of feature-based training records (e.g., those based on objects) and by developing a subset of information rich records that can support efforts to investigate questions relating to ecosystem dynamics (e.g., loss and degradation), and also to drivers of change and associated pressures. In coming years, *coastTrain* will continue to be expanded through targeted outreach to the global coastal research community and international initiatives relating to coastal conservation. Ultimately, we hope *coastTrain* provides a template to support efforts to map all of Earth's ecosystems [1,2,42] and their change using Earth observation archives.

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Data Availability Statement: The published release of *coastTrain* version 1.0 is available from Zenodo (https://doi.org/10.5281/zenodo.7080756, accessed on 15 September 2022). Issues and incremental updates are available via the GitHub *coastTrain* repository (https://github.com/nick-murray/coastTrain, accessed on 15 September 2022) and the interactive website (www.coasttrain.org, accessed on 15 September 2022).

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