Port Phillip Bay Habitat Map

Habitat Complex Modelling (CBiCS Level 3)

Marine Biodiversity Policy & Programs | Biodiversity Strategy and Knowledge | Biodiversity Division
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VICTORIA State Government | Environment, Land, Water and Planning

Acknowledgements

The Victorian Government proudly acknowledges Victoria’s Aboriginal communities and their rich culture and pays respect to their Elders past and present. We recognise the intrinsic connection of the Kulin nation people to Nairm (Port Phillip Bay) and its catchment, and we value their contribution in the management of land, water and the natural landscape. We support the need for genuine partnerships with Aboriginal people and communities, to understand their culture and connections to Country, and to better manage the Bay and its catchments. We embrace the spirit of reconciliation, working towards the equality of outcomes and ensuring an equal voice. DELWP would like to acknowledge and thank all individuals who provided data to support the outcomes of this work.

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Front cover: Marcia Riederer, DELWP

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

Port Phillip Bay Habitat Map

Habitat maps represent communities of marine species across Port Phillip Bay. They are developed from observation records and environmental variables by applying machine learning methods to build predictive models that estimate their distribution. Habitat maps support the monitoring and management of marine biodiversity and health in the region.

Habitat Models

Port Phillip Bay supports many different natural habitats. Along the foreshore are sandy beaches, rocky intertidal reefs, mud flats, mangroves and saltmarshes. Habitats within the Bay include seagrass meadows, rocky reefs, sponge gardens and unvegetated soft sediments (sands and silt). Unvegetated soft sediments on the seafloor are home to a diverse array of invertebrates and micro-organisms that are critical in processing nitrogen and other nutrients. Seagrasses provide nurseries for many fish and invertebrate species. Rocky reefs provide hard substrate on which hundreds of species of seaweed grow. The Bay provides habitats for a diversity of marine plants and animals, many of which are endemic. They include hundreds of species of fish, molluscs, crustaceans, marine worms, jellyfish, sea anemones, algae (seaweeds), sponges as well as seabirds, dolphins and little penguins.

The health of Port Phillip Bay and its marine and coastal areas are vital for Victoria and its people, providing invaluable benefits ecologically, recreationally, and economically. Mapping the distribution and extent of marine habitats in the Bay helps achieve a better understanding of the ecosystem to monitor and maintain ecological functions, ecosystem services and improve its overall health.

CoastKit

CoastKit is a new DELWP online platform for environmental managers and researchers, that synthesises and coastal scientific data and resources.

The spatial toolkit promotes standardised data classification for collection, reporting, monitoring and assessment across Victoria. CoastKit support marine managers by interactive tools that facilitate:

- Marine biotope distribution maps
- Cumulative risk assessments
- marine environmental impact assessments
- marine spatial planning
- ecsosytem modelling
- marine habitat
- ecosystem-based management (EBM)

Ultimately, CoastKit unifies and disseminates relevant information to improve the efficiency and effectiveness of decision making, ensuring the future health and sustainability of Victoria's unique marine and coastal assets.

Further information about CoastKit
https://mapshare.vic.gov.au/coastkit/

Habitat Classification System

The habitat map uses the Combined Biotope Classification Scheme (CBiCS) as developed and described by Edmunds and Flynn (2015, 2018; 2021). CBiCS has six, hierarchical classification components; Level 1 – Environment, Level 2 – Broad Habitat, Level 3 – Habitat Complex, Level 4 – Biotope Complex, Level 5 – Biotope, Level 6 – Sub-biotope. The hierarchical design (Figure 1) is adopted directly from the United Kingdom's Joint Nature Conservation Committee (JNCC) scheme that is a proven system for classification. With some conversion, many of the actual classes from the JNCC scheme that are mapped in Europe (e.g., seaweed biotopes, mussel, worm, and other biogenic reefs) were imported directly into the Australian context (Edmunds 2021). This scheme also aligns with the terrestrial Ecological Vegetation Class (EVC) system for recording mangrove and saltmarsh biotopes.

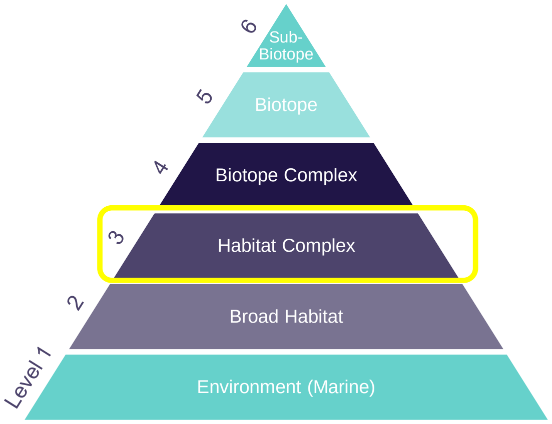

Figure 1. Hierarchical classification system. CBiCS classification components as outlined in Edmunds et al. (2021). Level 3 is highlighted in yellow to indicate the level the resulting habitat model was constructed.

Building Habitat Models

Habitat models were built to predict habitat distribution by applying machine learning tools which integrate ground truthed data and environmental predictors. Level 3 Habitat Complex was selected providing the lowest classification (Figure 1) with data availability to support a broad-scale model across Port Phillip Bay. Previous mapping of Port Phillip Bay has provided insight into habitats across the region, with the latest map produced in 2016 (Edmunds & Flynn 2018). Since then, additional benthic survey data and data on environmental predictors has developed which increases the capacity to improve mapping outputs. This work provides an updated broad-scale habitat map across Port Phillip Bay and offers a baseline for future data to build upon.

Ground-truth records

Ground-truth survey data provide the primary data to build the habitat model. Field observations of Victorian marine species and habitats are categorised according to the CBiCS method to the lowest hierarchical level where possible. Records are combined from various sources including habitat mapping, monitoring, impact assessments and historical ecological surveys. Across Port Phillip Bay 9,683 ground-truth records have currently been categorised to level 3 - Habitat Complex across the years 1969 to 2019 (Figure 2; Appendix Figure 1). These records can be explored spatially using the 'Biotope Atlas Tool' in CoastKit.

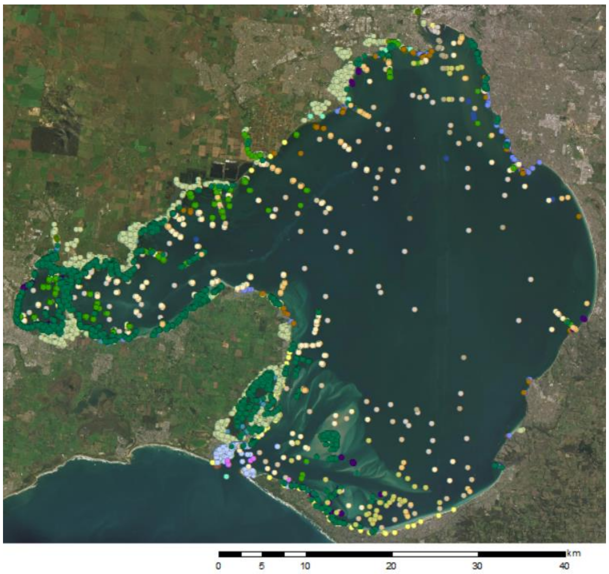

Figure 2: Ground truth samples (9683 records at level 3) in Port Philip Bay, Victoria. Base map source: ESRI, (2021). DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Created in ArcGIS (ESRI 2019).

Environmental predictors

Gridded data products that are at a high resolution across Port Phillip Bay and that are considered important predictors for marine habitats (i.e., biotope related fauna and flora) were included in the model (Table 1).

Environmental parameters were sourced from different methods including lidar, multibeam, and indexes calculated from the Digital Elevation Model (DEM), and mapped at a resolution of 2.5 metres (e.g., Figure 3). Predictor data were largely complete across the study region with few missing values (0-

5% of coverage), these values were filled by spline interpolation.

Table 2. Environmental Predictors used in habitat model. For full details of predictors see Appendix Table 1.

Environmental Predictor	Description
Aspect	Calculated using the differential weighted algorithm (Horn 1981) for DEMs
Bathymetry	DEM from lidar and multibeam data at 2.5 m resolution
Distance to Coast	Fetch 200 km offshore, approximated as the minimum distance from shore in one of the eight directions.
Energy	CBiCS energy classification ordinal layer based on tidal currents, swell ground surge and observed biotopes
Exposure	Wind power, fetch (km), and depth
Light Reflectance	Lidar Reflectance at 5 m grid resolution resampled to 2.5 m
Relief	Calculated using the DEM, as the greatest absolute difference between the centre cell and the surrounding cells
Ruggedness	Calculated using the DEM and a Terrain Ruggedness Index (TRI; Riley et al. 1999).
Rugosity	Rugosity was indexed by the square root of the sum of the residuals when slope and aspect (Horn 1981) were used to fit a plane to a 3 x 3 neighbourhood region and provide residuals above and below the plane
Sediment & Substratum	Compiled by Edmunds & Flynn (2018) from: Beasely (1966); Currie & Parry (1999); Poore (1992); Poore et al. (1975); Poore & Rainer (1976); Wilson et al. (1998); Cohen et al. (2000); Holdgate et al. (2001).
Slope	Calculated using the differential weighted algorithm of Horn (1981) for digital elevation models (DEMs)
Topographic Position Index	A modified topographic position index (Weiss 2001). Three topographic index scales were calculated: TPI a (5 m), TPI b – (25 m), TPI c (100 m).

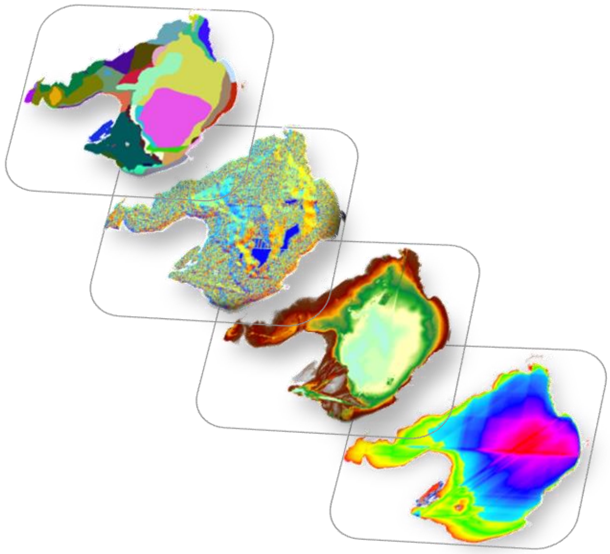

Figure 3. Examples of environmental predictor layers for Port Phillip Bay. Created in: ESRI (2019). ArcGIS Desktop: Release 10.8. Redlands, CA: Environmental Systems Research Institute.

Machine learning method

Random Forest is an ensemble model using bagging as the ensemble method and decision tree as the individual model (Breiman 2001). Ensemble models incorporates multiple models to make overall predictions, thus incorporates the variance within different models to give results that are less sensitive and that are more robust (less bias and less variance). Random Forest uses a bagging approach where subsets of the data are used to train each model in parallel (not sequential; Figure 4). Random Forest is not affected by correlated variables as per other modelling approaches as it uses a random selection of variables to build trees.

Random Forest is considered an effective modelling method for marine habitats and biodiversity with application across the globe, with high performance achieved in comparison to other methods (Wei et al. 2010; Pitcher et al. 2012; Peterson & Herkul 2017; McLaren et al. 2019). To map the multiple habitat types for the Level 3 Habitat complex in Port Phillip Bay, the Random Forest classification algorithm was used. Analyses were implemented in the R computing environment (R Core Team, 2021) using package “randomForest” (Liaw & Wiener, 2002). A total of 8,325 ground-truth records were used within the model (of the 9,683 records) that met the Random Forest modelling criteria (≥5 unique values for each biotope category; Breiman 2001).

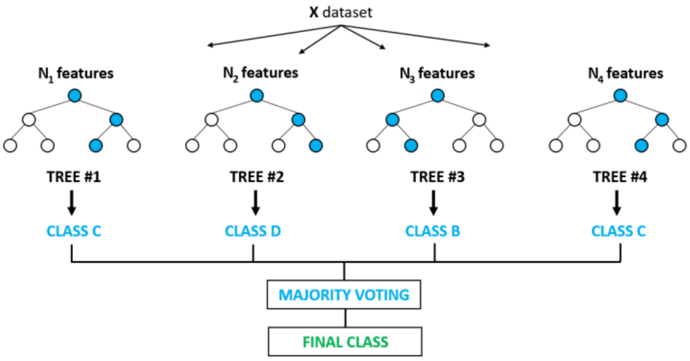

Figure 4. Random Forest Classification. Source: Martinez, E. et al. (2018).

Parameter tuning

The Random Forest algorithm can be tuned according to parameter settings. A grid search approach was applied based on the out-of-bag (OOB) estimate of error to optimize the random forest parameters. Three parameter which are considered to influence the model were tuned; 1) The number of variables randomly sampled as candidates at each split (*mtry*), 2) the number of trees to grow (*ntree*), and the maximum number of terminal nodes that trees in the forest can have (*maxnodes*).

Validation

Random Forest has inbuilt cross-validation using bootstrapping. By default, Random Forest picks up two-thirds of the data for training and rest for testing. Trees are also constructed from randomised variable selection and is not prone to overfit unlike other models.

Habitat Complex Map (CBiCS Level 3)

The resulting Level 3 Habitat Complex map is presented in Figure 5. Here the model represents 19 different habitat complexes at Level 3. The most dominant habitat types are sublittoral sand and muddy sand (ba5.2) and sublittoral mud (ba5.3) within the centre of the bay. However, a diversity of habitats are observed with other prominent habitats of sublittoral seaweed on sediment (ba5.7) which supports various seaweed communities as well as drift algae mats, and non-reef sediment epibenthos (ba5.b) characterised by mixed sublittoral sediments covered by epibenthic biota including scallop beds, seapen beds, *Pyura* and ascidians. The entrance of the Bay is uniquely characterised by moderate energy infralittoral rock (ba3.2) as well as patches of sublittoral seagrass beds (ba5.8; genera *Cymodocea, Halophila, Posidonia, Ruppia*, *Thalassia, Zostera*), which are found near the coastline, particularly around Corio Bay. Saltmarsh and reedbeds (ba2.5; Boon et al. 2011), and mangroves (ba2.6; Edmunds & Flynn 2018) were not modelled in this study due to their different environmental variables as well as their well described distribution, these data were therefore joined to the habitat map after the modelling process. Several features of the bay such as the shipping channel and dredging areas were sections that were extracted from the habitat modelling process due to the altered habitat composition in these areas. These areas are depicted in grey.

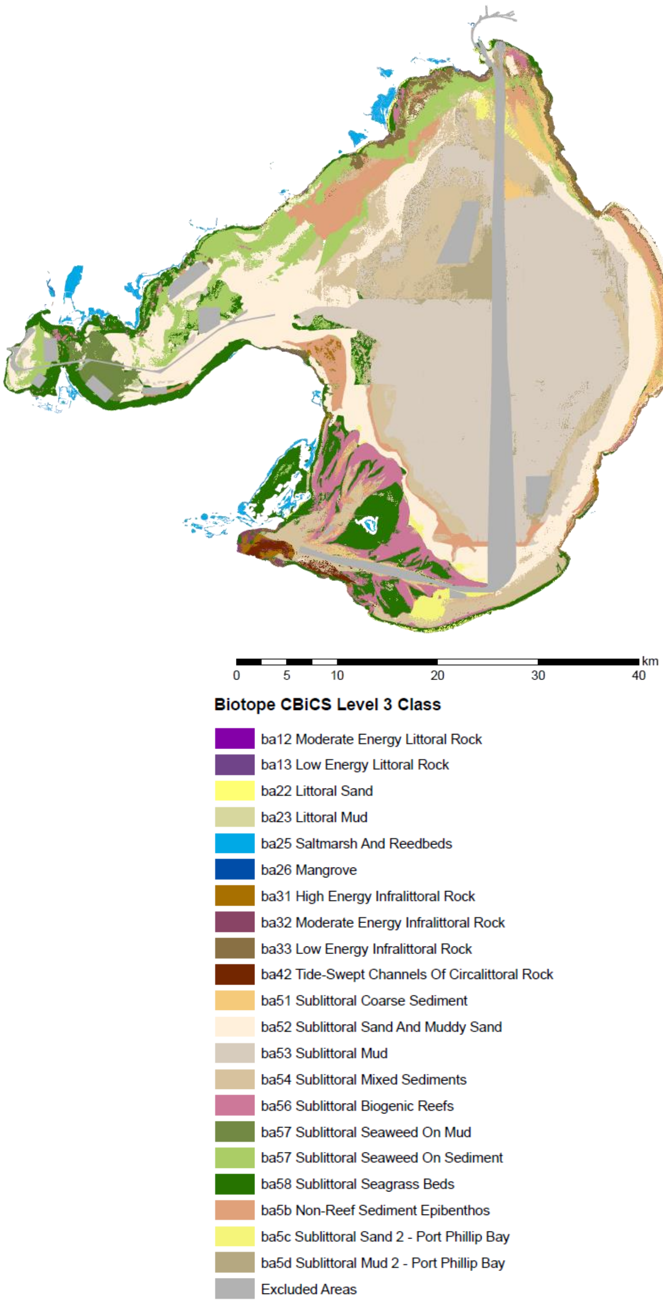

Figure 5. Habitat map of Port Phillip Bay (Level 3 CBiCS). Created in R (R Core Team, 2021) and mapped in ArcGIS (ESRI 2019). Coordinate system: WGS 1984 UTM Zone 55S.

Map accuracy and uncertainty

Random forest modelling produced an accuracy (Out-of-bag) of 91%. Bathymetry, substratum, sediment, and distance were the most important predictors in the model (Appendix Figure 2). For full a full description of habitat classes and their prediction user and producer accuracy as well as error commission and omission please see the Appendix Table 2. The resulting raster data were processed into polygon data using the ArcGIS Conversion and Cartography tool sets (ESRI 2019; Appendix Figure 3). Polygon data were aggregated at 25 metres and do not represent the fine resolution from the raster data (2.5m; available for download from CoastKit). The polygonised data were also assessed against previous mapping products across the bay, satellite imagery and marine navigation charts, with small edits made for alignment.

Limitations of the model include the reliance upon past ground-truthed data, where habitat changes and shifts may have occurred. Habitat areas depicted in this model may also represent areas which are suitable for particular habitats, however, they may not exist in that exact location. For example, seagrass is largely ephemeral in the Bay varies where its growth is influenced by environmental conditions. Habitats represented at CBiCS level 3 will also comprise a mosaic of biotopes and in some cases the represented habitat will not accurately define the integrated habitat complexes. Similarly, the model relies upon environmental variables to find a niche of suitable parameters that characterise the habitat complex within the Bay. Hence, inclusion of other environmental variables may improve the accuracy of the results and importantly environmental variables also contain some degree of uncertainty.

Habitat Map Applications

The habitat complex (Level 3 CBiCS) map supports knowledge of the broad scale distributions and extent of marine habitats within Port Phillip Bay. Importantly, these habitats encompass a range of other species, for example sublittoral seagrass beds (ba5.8) may contains a diversity of seagrass species including genera *Cymodocea, Halophila, Posidonia, Ruppia, Thalassia, Zostera*, which are not depicted individually in the model. Some of these species may be more vulnerable than others, and some may or may not be present within the habitat complex that is mapped. The map should be used at broad scales of >25 m, and where detailed work of habitat types is needed, for example to examine the potential impacts of developments, finer resolution mapping is required as well as those that depict lower levels of CBiCS classification (i.e., level 4 and 5). However, the map also serves as a first indicator of the potential presence of vulnerable or rare habitats that may exist within the larger habitat complex, and marks areas where further detailed mapping could be undertaken. The current habitat map presented here provides broad habitat complexes across the bay and provides greater knowledge of the diversity across the bay as whole. This work can support the management of large-scale habitat complexes, their condition, and their alignment with other broad scale processes across the bay.

Continuous Improvements

Habitat models can be easily improved as more ground-truth data are obtained. Similarly, the incorporation of relevant environmental predictor data such as hydrodynamics and satellite imagery can help improve model performance. Finer resolutions models and habitat maps to CBiCS level 4 to 6, can be achieved with the availability of more data. The habitat model (level 3) and resulting map provides an updated broad-scale habitat map across Port Phillip Bay and provide a baseline for future data to build upon.

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Appendix

Table 1. Environmental predictors

Predictors	Description
Bathymetry, Digital Elevation Model (DEM)	The data provided by DELWP included tiles of mixed lidar and multibeam data from 0.5 to 5 m grid resolution, (universal transverse Mercator projection, WGS84) and a state-wide combined product that included other hydrographic data at 10 m grid resolution (conical Lambertian projection - Vic Grid). The provided tiles were 10 x 10 km, and the tiling were set as a standard for state-wide raster mapping of marine habitats and biota. All provided data had a vertical datum of mean sea level (MSL). Lidar data for Gippsland Lakes was provided by DELWP separately and inserted into the DEM. The state-wide 10 m resolution grid was converted to Universal Transverse Mercator projection and tiled into 10 x 10 km tiles for zones 54 and 55 in Victoria. All data were then either up-scaled or down-scaled to a 2.5 m grid resolution in 10 x 10 km tiles. This resolution was chosen as being fine enough to map key marine habitats, particularly in the littoral zone, and be practical for data retrieval and computational analyses at a state-wide level. Data were down-scaled using bilinear interpolation and up-scaled using bicubic interpolation, with modelling and sharpening using a dual-tree discrete wavelet transform. A standard set of DEM tiles were then constructed by first constructing a set of blank tiles for the State, adding the down-scaled (high resolution) data and then filling the missing cells with the upscaled data. The Gippsland Lakes data were then inserted. The DEM was then converted from a vertical datum of mean sea level (MSL) to lowest astronomical tide (LAT) using spatial interpolations from the Australian Coastal Vertical Datum Tool. The interpolation points were derived from the spatial position of break points in the corrections from the tool. The standard tiles are divided into UTM Zone 54 and Zone 55 and saved as 4k x 4k byte arrays (.bin) with separate header (.hdr) and projection (.prj) files suitable for direct import to any GIS software. The position of the top left corner of the tile is indicated in the file name, enabling scripted and automatic data retrieval and handling.
Lidar Reflectance	Lidar Reflectance was collected at 5 m grid resolution but was upscaled to 2.5 m resolution into tiles matching the DEM. The upscaling method was the same as for the bathymetry. The lidar reflectance data was not radiometrically corrected for depth and this should be considered for most habitat mapping purposes that cross ecological depth zones.
Slope and Aspect	Fine-scale slope and aspect were calculated using the differential weighted algorithm of Horn (1981) for digital elevation models (DEMs). The algorithm was applied to a 3 x 3 grid of cell size 2.5 m.
Rugosity	Rugosity was derived to provide a roughness measure relatively independent of slope, as opposed to most other texture indicators. In this case, the Horn slope and aspect was used to fit a plane to the 3 x 3 neighbourhood region and provide residuals above and below the plane. Rugosity was indexed by the square root of the sum of the residuals.
Ruggedness and Relief	Fine scale relief and ruggedness was calculated from the DEM using a 3 x 3 m grid of cells. Although the horizontal scale of the indices could be determined by a step size between the cells, the calculation only used direct neighbours (matching slope, aspect and rugosity). For each centre cell, the elevation at the eight surrounding cells was extracted. Relief was calculated as the greatest absolute difference between the centre cell and the surrounding cells. Ruggedness was indicated using Riley et al. (1999) Terrain Ruggedness Index (TRI). This was calculated as the average of the squared elevation differences between the centre cell and the eight surrounding cells.

Topographic Position Index	A modified topographic position index (Weiss 2001) was used so the index could be calculated and compared at different scales. In this case the calculations were derived from a circle of a selected number of points at a selected distance from a centre cell. Data from a selected distance was used rather than the more traditional method of integrating data from the whole area within the circle, or from the area within an annulus, so that different scaled data are not confounded by the inclusion of data close to the centre cell. The circular data was extracted according to the estimated elevation of a point from each selected direction and radius from the centre cell. This was estimated using bilinear interpolation from the four DEM cells surrounding the radius point of interest. Each index was calculated using 32 radials from the centre cell. Three topographic index scales were calculated: TPI a - fine = 5 m (2 cell radius) TPI b - medium = 25 m (10 cell radius) TPI c - coarse = 100 m (40 cell radius)
Distance from Shore, Fetch and Exposure	Distance from shore, Fetch and Exposure was calculated using the DEM downscaled to 10 m grid scale then upscaled back to the standard tiles and scales. The downscaling was done to enable practical integral calculations over larger areas of the coast. All calculations were clamped at 60 km from the coast. A fetch index was calculated for each DEM cell as the sum of all distance steps to shore, in 8-point compass rose directions, out to the 60 m arbitrary limit. The fetch was modified in shallow water < 5 m by a ramp function to account for wave breaking and sheltering by shoaling waters. Distance from shore was approximated as the minimum distance from shore in one of the eight directions. A relative exposure index was derived by integrating wind power with the fetch for each of the eight directions. The calculation used wind roses provided by the Bureau of Meteorology for the locations of Mt Gambier, Cape Nelson, Warrnambool, Cape Otway, Lorne, Aireys Inlet, Queenscliff, Avalon, Melbourne, Cape Schanck, Wilsons Promontory, Lakes Entrance, Point Hicks and Gabo Island. The wind speeds were converted to an approximation of power using the cube of speed in metres per second, weighted by the frequency of occurrence for each wind speed category and totalled for each direction. The exposure index was calculated for each cell as a product of the wind power and the fetch, summed over each of the eight directions. A gaussian smoothing function was then used to remove some of the quantisation imposed by the small number of directions assessed.
Sediment & Substratum	Compiled by Edmunds & Flynn (2018) from: Beasely (1966); Currie & Parry (1999); Poore (1992); Poore et al. (1975); Poore & Rainer (1976); Wilson et al. (1998); Cohen et al. (2000); Holdgate et al. (2001).
Energy	CBiCS energy classification ordinal layer based on tidal currents, swell ground surge and observed biotopes. The open coast is classified as high energy and embayment's are low energy, with moderate energy zones connecting the high and low zones. In Victoria, there are not that many moderate energy zones, for Port Phillip Bay these include Port Phillip Heads (inside Rip Bank to northern edge of Great Sands and eastward to Rosebud).

Table 2. The Random Forest habitat model accuracy, overall accuracy of 91%.

	ba11	ba12	ba13	ba22	ba23	ba26	ba31	ba32	ba33	ba42	ba51	ba52	ba53	ba54	ba56	ba57	ba58	ba5b	ba5c	ba5d	User Accuracy %	Error Commission %
ba11	60	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98.36	1.64
ba12	0	28	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	87.50	12.50
ba13	0	0	249	1	0	0	0	0	2	0	0	0	0	0	1	0	6	0	0	0	96.14	3.86
ba22	0	0	2	67	0	0	0	0	1	0	0	0	0	0	0	0	25	0	0	0	70.53	29.47
ba23	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	29.41	70.59
ba26	0	0	2	2	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	33.33	66.67
ba31	0	0	1	0	0	0	342	30	0	1	0	2	0	0	0	0	0	0	0	0	90.96	9.04
ba32	0	0	0	0	0	0	43	655	0	0	0	0	0	0	0	0	9	0	1	0	92.51	7.49
ba33	0	0	8	1	0	0	0	0	282	0	0	8	0	0	1	8	20	3	0	0	85.20	14.80
ba42	0	0	0	0	0	0	1	2	0	2	0	0	0	1	0	0	0	0	0	0	33.33	66.67
ba51	0	0	0	0	0	0	0	0	1	0	8	2	1	0	0	2	0	3	0	0	47.06	52.94
ba52	0	0	0	0	0	0	1	1	11	0	0	1741	0	1	1	28	73	5	0	0	93.50	6.50
ba53	0	0	0	0	0	0	0	0	0	0	0	19	28	3	0	13	1	0	0	5	40.58	59.42
ba54	0	0	0	0	0	0	0	1	0	1	0	14	6	5	0	1	5	9	5	0	10.64	89.36
ba56	0	0	1	1	0	0	0	0	2	0	0	1	0	1	50	3	26	6	0	0	54.95	45.05
ba57	0	0	0	1	0	0	0	0	7	0	1	50	1	2	2	985	26	7	0	0	91.04	8.96
ba58	0	0	2	2	0	0	0	20	7	0	1	65	0	0	9	22	2738	2	1	0	95.43	4.57
ba5b	0	0	0	0	0	0	0	0	4	0	0	4	1	1	3	9	5	275	2	0	90.46	9.54
ba5c	0	0	0	0	0	0	0	0	0	0	0	7	0	1	1	2	3	2	33	0	67.35	32.65
ba5d	0	0	0	0	0	0	0	0	0	0	0	2	7	2	0	0	0	0	0	13	54.17	45.83
Producer Accuracy %	100.00	96.55	93.26	89.33	100.00	100.00	88.37	92.12	88.96	50.00	80.00	90.91	63.64	29.41	73.53	91.80	92.41	88.14	78.57	72.22	**Overall Accuracy 91%**	
Error Omission %	0.00	3.45	6.74	10.67	0.00	0.00	11.63	7.88	11.04	50.00	20.00	9.09	36.36	70.59	26.47	8.20	7.59	11.86	21.43	27.78		

Figure 1. Ground-truth records across Port Phillip Bay (biotope level 3 habitat level) sampled per year from 1969 to 2019.

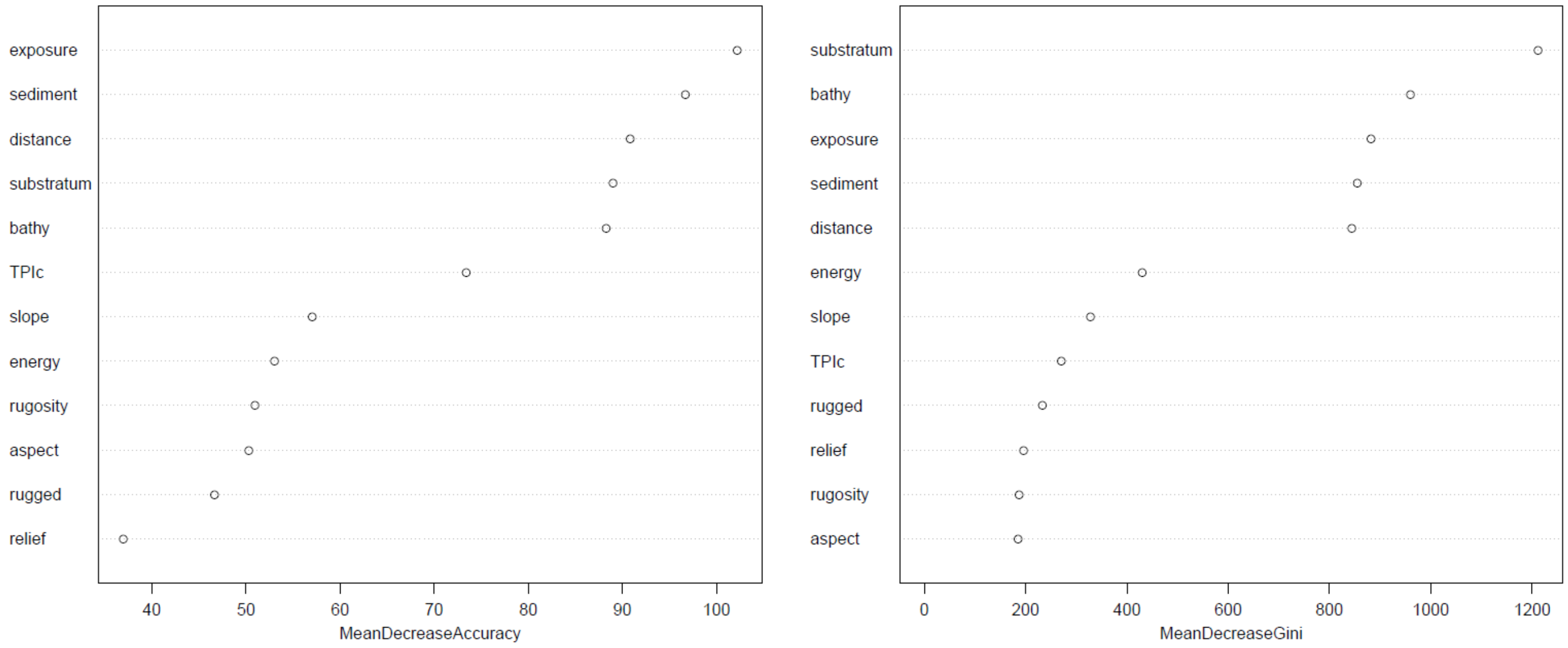

Figure 2. Environmental predictor importance from the Random Forest model. Bathymetry, substratum, sediment and distance were the most important predictors in the model.

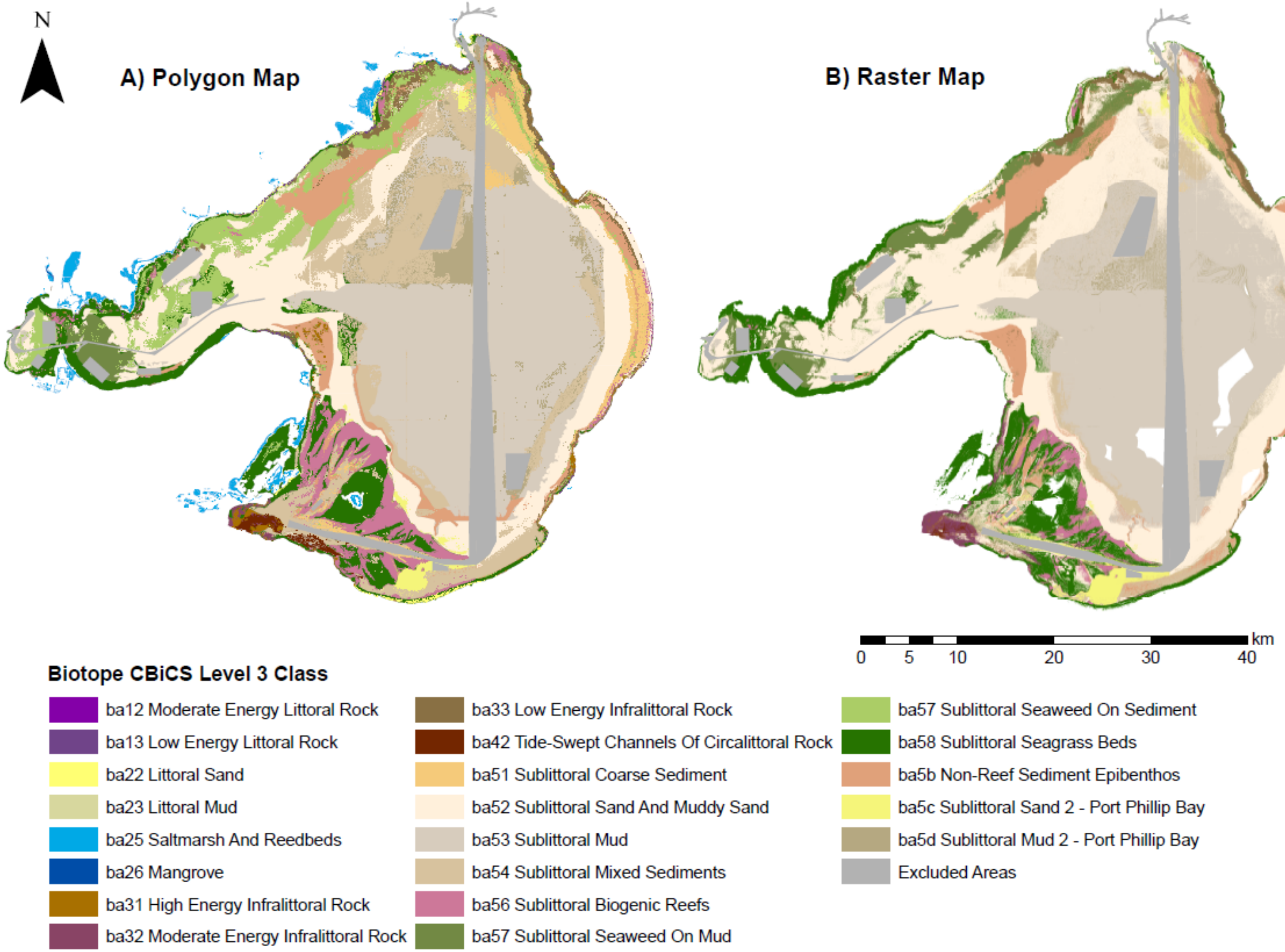

Figure 3. Habitat map of Port Phillip Bay (Level 3 CBiCS). Created in R (R Core Team, 2021) and mapped in ArcGIS (ESRI 2019). Coordinate system: WGS 1984 UTM Zone 55S; **A)** polygon data aggregated at 25 metres with minor edits made to align with previous mapping products across the bay, satellite imagery and marine navigation charts **B)** fine resolution raster (2.5m; available for download from CoastKit) output from random forest classification model.