Fetch and relative wave exposure indices for the coastal zones of the Scotian Shelf-Bay of Fundy and Newfoundland-Labrador Shelves bioregions

Background

Exposure to wind-driven waves is an important physical feature of nearshore aquatic environments that influences both ecological communities and human activities. Wave exposure can influence sediment dynamics and plays an important role in structuring biological communities in these environments through physical disturbance (Keddy 1983, Theuerkauf et al. 2017). For example, gradients in wave exposure are associated with patterns of diversity, abundance, and distribution of invertebrate communities along rocky shores (Norderhaug et al. 2012, Arribas et al. 2014). Exposure also influences important vegetated biogenic habitats such as seagrass and kelp beds through effects on primary productivity (Krumhansl & Scheibling 2011a, Krumhansl et al. 2021), resilience (Krumhansl et al. 2021), distribution and landscape patterns (Fonseca & Bell 1998, Bekkby et al. 2008), detrital export (Krumhansl & Scheibling 2011a), and rates of herbivory (Krumhansl & Scheibling 2011b, Frey & Gagnon 2015). Spatial variation and changes in the wave environment also impact human use of the coastal zone. For example, exposure factors into siting of ocean-based aquaculture operations (Lader et al. 2017) and decisions related to the development and adaptation of coastal infrastructure in the face of a changing climate (Hatcher & Forbes 2015). Therefore, the availability of wave exposure indices with regional coverage at a relatively high spatial resolution is essential for marine spatial planning decisions that guide the use of coastal ocean resources.

Methods

We calculated a relative exposure index (REI) for wind-driven waves covering the coastal zones (5-km from coastline) of the Newfoundland-Labrador Shelves and Scotian Shelf-Bay of Fundy bioregions using methods adapted from Keddy (1982) and Fonseca & Bell (1998). We derived REI and two other indices (sum fetch, minimum fetch) from wind fetch calculations for input points in an evenly spaced fishnet grid covering the 5-km buffered areas (see linked region-specific records for differences in input point selection, spatial resolution, and data pre-processing methods)

Wind fetch constrains the potential for wind-driven waves to build and is defined here as the distance from a point to land along a given compass heading (Shore Protection Manual 1975). For each input point, we measured fetch (m) along 32 equally spaced compass headings (11.25° intervals) to a maximum distance of 300 km. Fetch was calculated using either a Python script adapted from the Department of Fisheries and Oceans Marine Spatial Ecology and Analysis Group (2014) or with R code written by O'Brien et al. (2022) by first generating a 300-km line segment in the *i*th direction originating at the input point before clipping by a combined land polygon feature layer to erase segments intersecting land features (see linked data records below for description of input land polygon features). The line feature segments intersecting the original input point were retained and measured and all other segments were excluded. We also calculated the sum and minimum of all 32 unweighted fetch lengths for each point, which provide coarse proxies of wave exposure and distance to land, respectively. To calculate REI, we combined calculated fetch with modelled wind data as:

$$REI \ = \ \Sigma_i^8 \ (V_i \times P_i \times F_i)$$

where *i* is the compass heading in 45° intervals (centred on N, NE, E, SE, etc.) ,*V* is wind speed (m s^{-1}), *P* is wind frequency, and *F* is effective fetch in the *i*th compass heading. Effective fetch is a directionally weighted average of the fetch distances adjacent to and including a given compass heading (Saville 1954, Shoreline Protection Manual 1975). Effective fetch reduces the influence of irregular shoreline shape on fetch calculations where long and narrow features (i.e., fetch length is much larger than fetch width) can result in an overestimate of fetch (Keddy 1982). For each of the 8 compass headings (*i*), we computed effective fetch (m) from the original 32 unweighted fetch distances as:

$$F_i \ = \ \frac{\Sigma_{j=1}^9 X_j \ \times \ cos\alpha_j}{\Sigma_{j=1}^9 \ cos\alpha_j}$$

where *j* is the 11.25° increment (n = 9) on either side of and including the compass heading *i*, *X* is fetch (m), and α is the angle of the *j*th departure from the *i*th compass heading. Modelled wind data (ERA5 reanalysis product for 2011-2020) were downloaded from the Copernicus Climate Data Store (Hersbach et al. 2018) and summarized in R using R code generated by O'Brien et al. (2022). Hourly predictions of the merdional (u) and zonal (v) components from 10 m above the sea surface were used to calculate hourly wind speed (m s^{-1}) and direction as

$$wind\ speed = \ \sqrt[2]{u^2 + \ v^2}$$

$$wind\ direction = \ mod\left(180 + \frac{180}{\pi}\text{atan2}(v, u), 360\right)$$

The hourly data were then binned in 45° intervals and summarized to obtain the average maximum daily wind speed and frequency of wind from the 8 compass headings used in the effective fetch calculations. We only included exceedance winds in calculations (predicted wind speeds in 95^{th} percentile). Average maximum daily wind speed was calculated as a grand mean of monthly averaged maximum daily wind speeds over the period from 2011 to 2020 and frequency as the proportion of predictions coming from the *i*th compass heading. The summarized data were interpolated from their original spatial resolution (0.25°) using the regularized spline method in ArcGIS Pro with the weight parameter set to 0.1 and an output cell size set to the same spatial resolution as the fetch data. Separate interpolations were made for each combination of wind parameter (i.e., average maximum daily wind speed, frequency) and compass heading (N, NE, E, SE, S, SW, W, NW) . Interpolated wind data were then combined with effective fetch to calculate REI and the resulting points features were converted to raster format and scaled between 0 and 1 (0 – most protected, 1 – most exposed).

In the linked data records for each bioregion below, we provide the scaled REI raster layer (GeoTIFF) along with the original calculations of unweighted fetch, effective fetch, and other fetch-based indices (i.e., sum, minimum) in csv format.