10.2. Pelagic Regionalisation

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1. Introduction

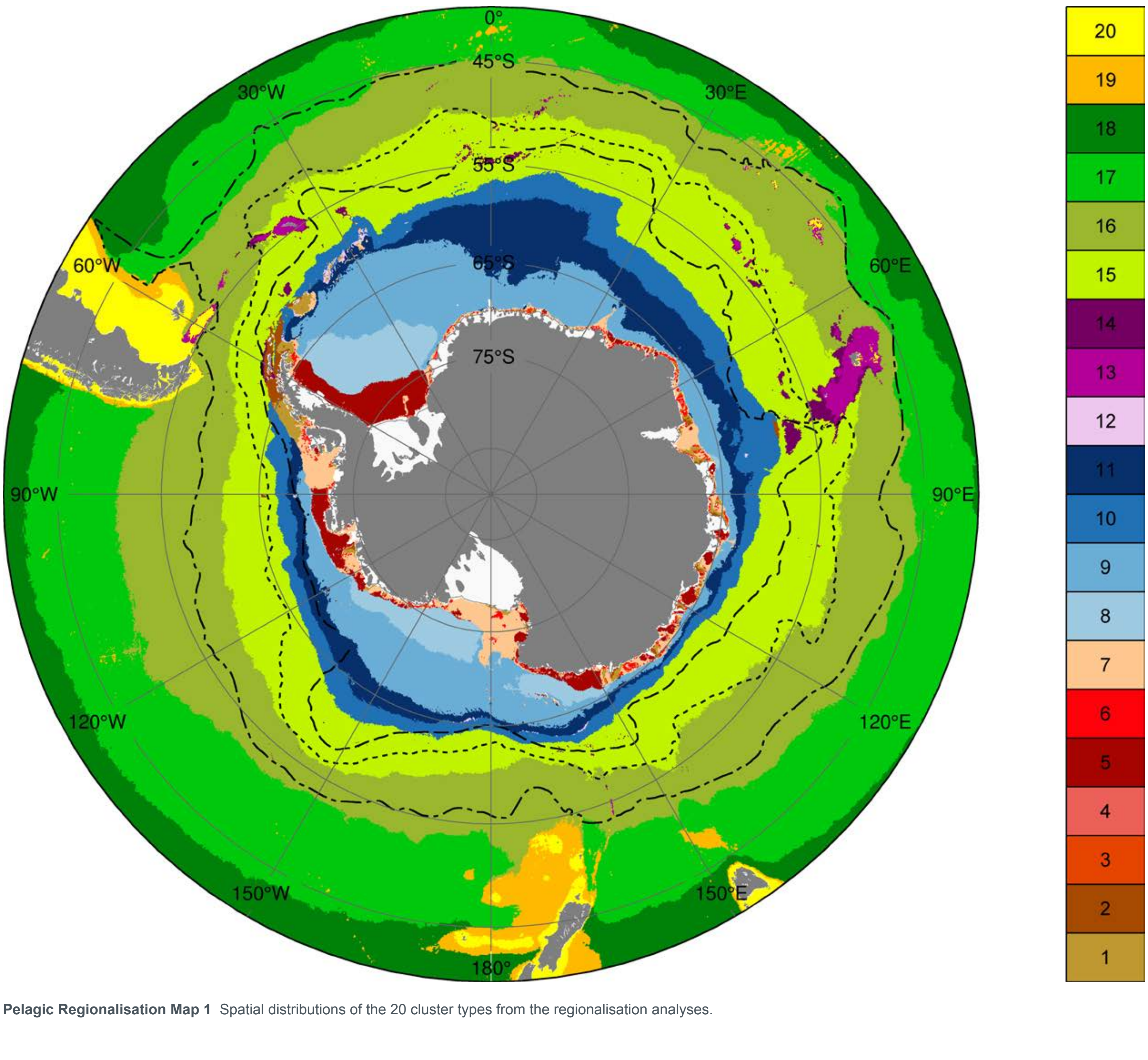
Regionalisation analyses are used to classify the environments across a region into a number of discrete classes, thereby providing a spatial and environmental subdivision of the study area. The classification is made on the basis of a number of environmental datasets, thereby providing an integrated description of the types of habitats characterised by those data. These types of analyses are typically undertaken as part of spatial management and modelling activities. This section presents the circumpolar primary pelagic regionalisation from Raymond (2011). It provides an update to earlier pelagic regionalisation work (Grant *et al.* 2006), and follows the advice from the Scientific Committee in 2010 that such analyses should consider depth, water mass characteristics, and dynamic ice behaviour (SC-CAMLR-XXIX 2010).

2. Methods

The methods for regionalisation follow those of Grant *et al.* (2006) and the CCAMLR Bioregionalisation Workshop (SC-CAMLR-XXVI 2007). Briefly, a non-hierarchical clustering algorithm was used to reduce the full set of grid cells to 250 clusters. These 250 clusters were then further refined using a hierarchical (UPGMA) clustering algorithm. The first, non-hierarchical, clustering step is an efficient way of reducing the large number of grid cells, so that the subsequent hierarchical clustering step is tractable. The hierarchical clustering algorithm produces a dendrogram, which can be used to guide the clustering process (e.g. choices of data layers and number of clusters) but is difficult to use with large data sets. Analyses were conducted in Matlab (Mathworks, Natick MA, 2011) and R (R Foundation for Statistical Computing, Vienna 2009).

Earlier work (Grant *et al.* 2006) used depth, sea surface temperature (SST), and subsurface (200 m) nutrient data. The nutrient data were both spatially smoothed (based on relatively sparse historical CTD data) and missing in near-coastal shallow areas. Here, three variables were used as input variables: summer climatological SST, depth, and the proportion of time covered by sea ice (see Chapter 2 for data details). Sea surface temperature was used as a general indicator of water masses and of Southern Ocean fronts (Moore *et al.* 1999, Kostianoy *et al.* 2004). Sea surface height (SSH) from satellite altimetry is also commonly used for this purpose (e.g. Sokolov & Rintoul 2009), and may give front positions that better match those from subsurface hydrography than does SST. However, SSH data has incomplete coverage in some near-coastal areas (particularly in the Weddell and Ross seas) and so in the interests of completeness, SST was used here.

During the hierarchical clustering step, singleton clusters (clusters comprised of only one datum) were merged back into their parent cluster (5 instances, in cluster groups 2, 3, 8, and 13). Additionally, two branches of the dendrogram relating to temperate shelf areas (around South America, New Zealand, and Tasmania) were merged to reduce detail in these areas (since such detail is largely irrelevant in the broader Southern Ocean context).



Pelagic Regionalisation Map 1 Spatial distributions of the 20 cluster types from the regionalisation analyses.

3. Results

20 environmental types were apparent in the results (Map 1, Figures 1–2), and are summarised in Table 1.

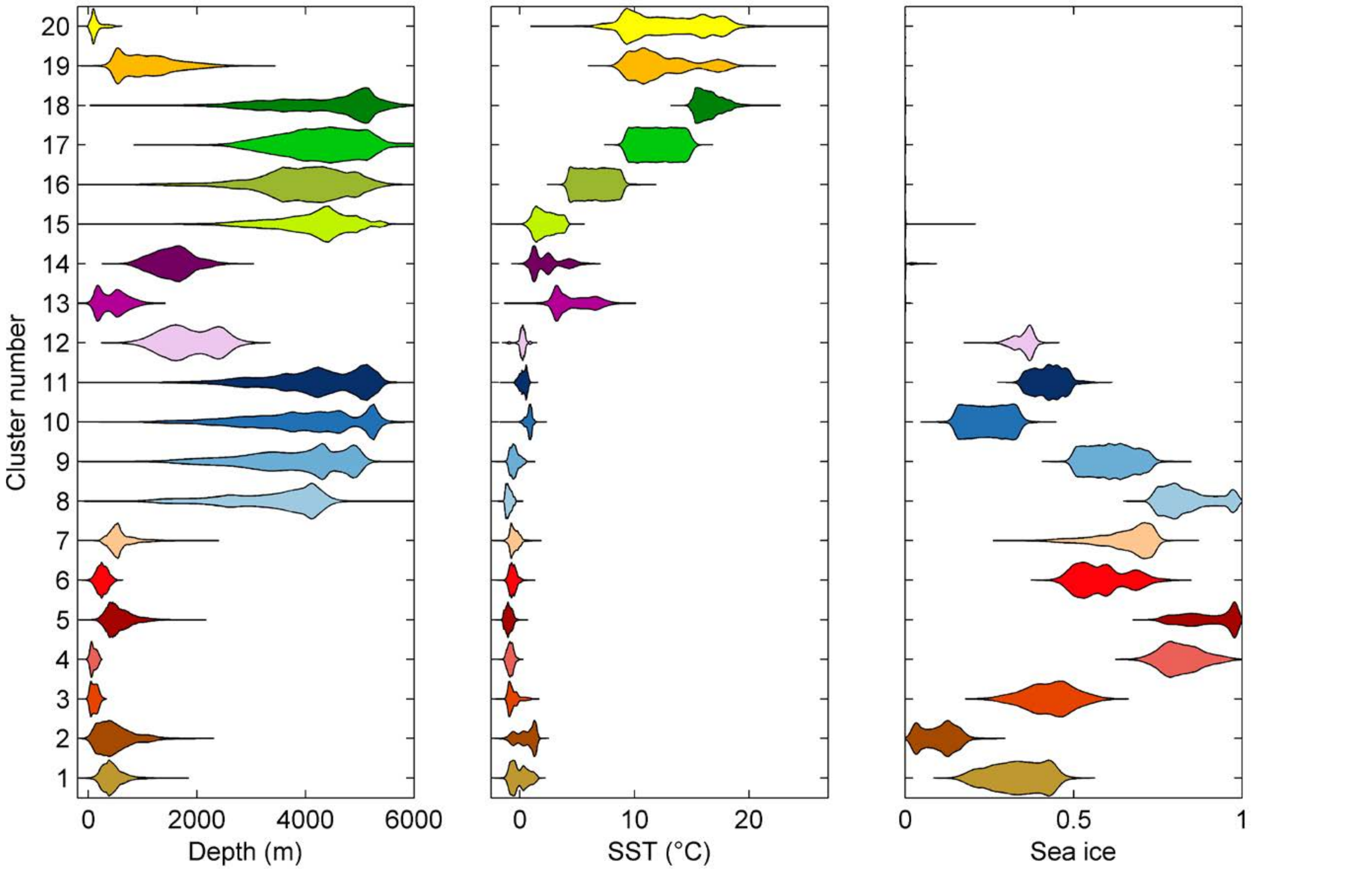


Figure 1 Dendrogram from the hierarchical clustering step. The dotted red line shows the level at which the dendrogram was cut to produce the groups. Note that clusters 19 and 20 represent merged clusters, to reduce detail in temperate shelf areas.

Table 1 Summaries of the 20 cluster types.

Cluster number	Description	Area (x1000 km^2)
1	Polynya margins on the continental shelf, the South Orkneys plateau, and areas off Adelaide and Biscoe Island in the West Antarctic Peninsula. Moderately shallow (to ~1000 m) with ice cover ~20–50% and SST <2°C.	287
2	Polynyas on the continental shelf, as well as areas off the Danco Coast of the Peninsula and the South Orkney Islands, and part of Banzare Bank. Low ice cover (~0–20%) and cold sea surface temperatures (<2°C).	167
3	Shallow shelf areas with ~25–60% ice cover. Restricted distribution, generally limited to East Antarctica.	33.1
4	Shallow areas with high ice cover (~75–95%). Patchy distribution scattered around the continental shelf.	42.8
5	Shelf areas with almost perennial ice cover (~75–100%).	1010
6	Similar to 7, but shallower and with lower ice cover. Widely but sparsely distributed around the continental shelf.	165
7	Moderate depths (~200–1000 m) and ice cover (~50–75%). Many areas correspond to general regions around polynyas (see e.g. Arrigo & van Dijken 2003). Also areas of the southern Scotia Arc.	1030
8–11	Sea ice zone. Clusters 8–11 form an approximately latitudinal, deep water continuum of increasing ice cover and decreasing SST. The northernmost limit (of cluster 10) is generally just south of the mean maximum winter sea ice extent.	8: 1670 9: 5140 10: 3430 11: 3570 Total: 13800
12	Moderate depth (~1000–2500 m) and sea ice cover (~40%). Restricted to parts of the southern Scotia Arc, and isolated pockets north of the Balleny Islands and off the West Ice Shelf.	48.9
13,14	13: Shallow (~200–1000 m) parts of the northern Kerguelen, Crozet, and South Georgia plateau areas, Conrad Rise. 14: Deeper (~500–2000 m) parts of the same plateaus, also Bouvetøya and the northern tip of the southern Kerguelen plateau.	13: 398 14: 345 Total: 743
15	Deep oceanic waters, encompassing approximately the southern Antarctic Circumpolar Current front and the Polar Front.	14500
16	Deep oceanic waters, bounded approximately on the north by the Sub-Antarctic Front.	16800
17,18	Temperate waters	17: 17900 18: 6560 Total: 24400
19	Outer areas of the South American, New Zealand, and Tasmanian shelves, and scattered temperate banks.	1420
20	Broad distribution around the South American, New Zealand, Tasmanian, and Crozet shelves. Shallow, ice-free, and with warm SST (~10–20°C).	1500

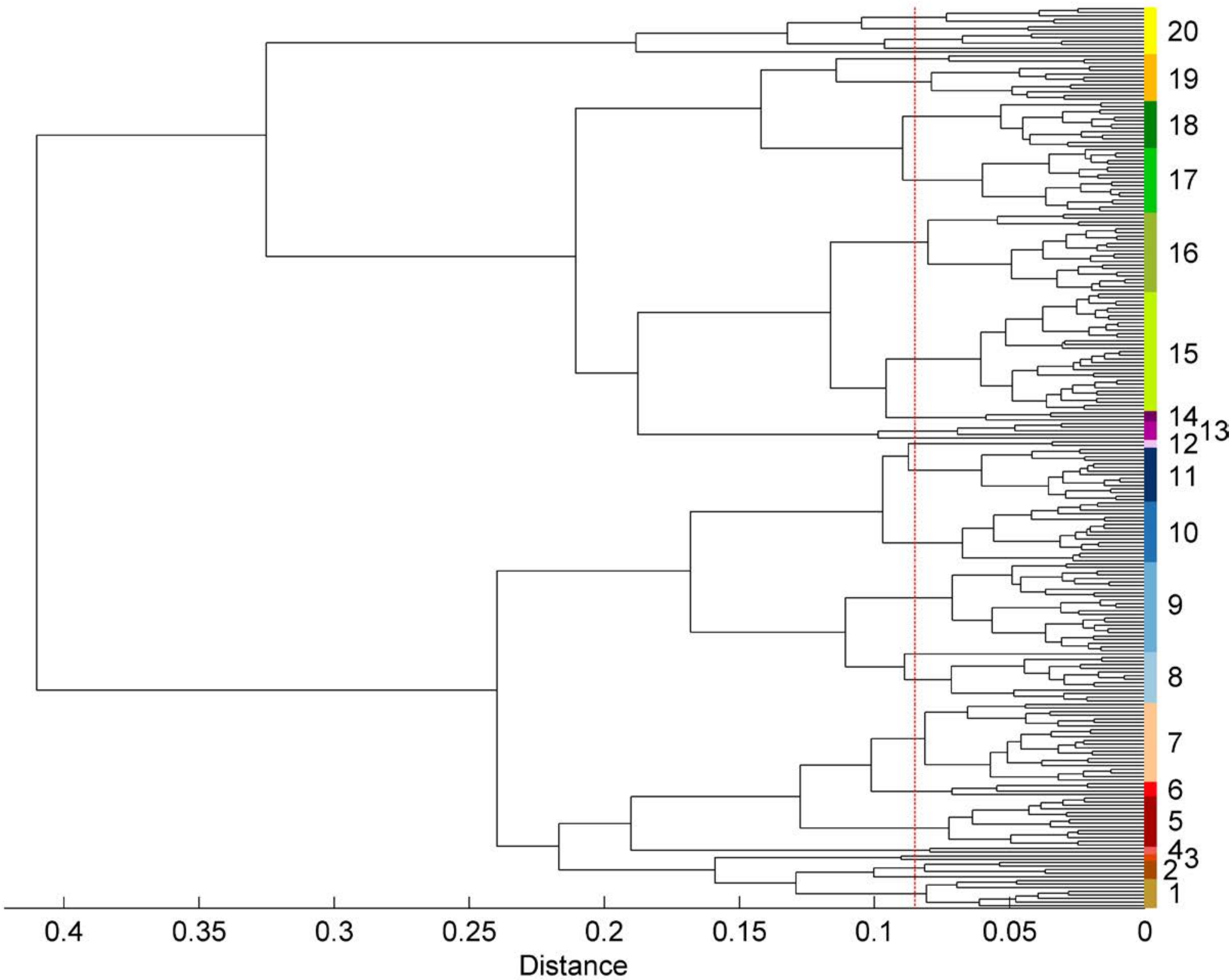
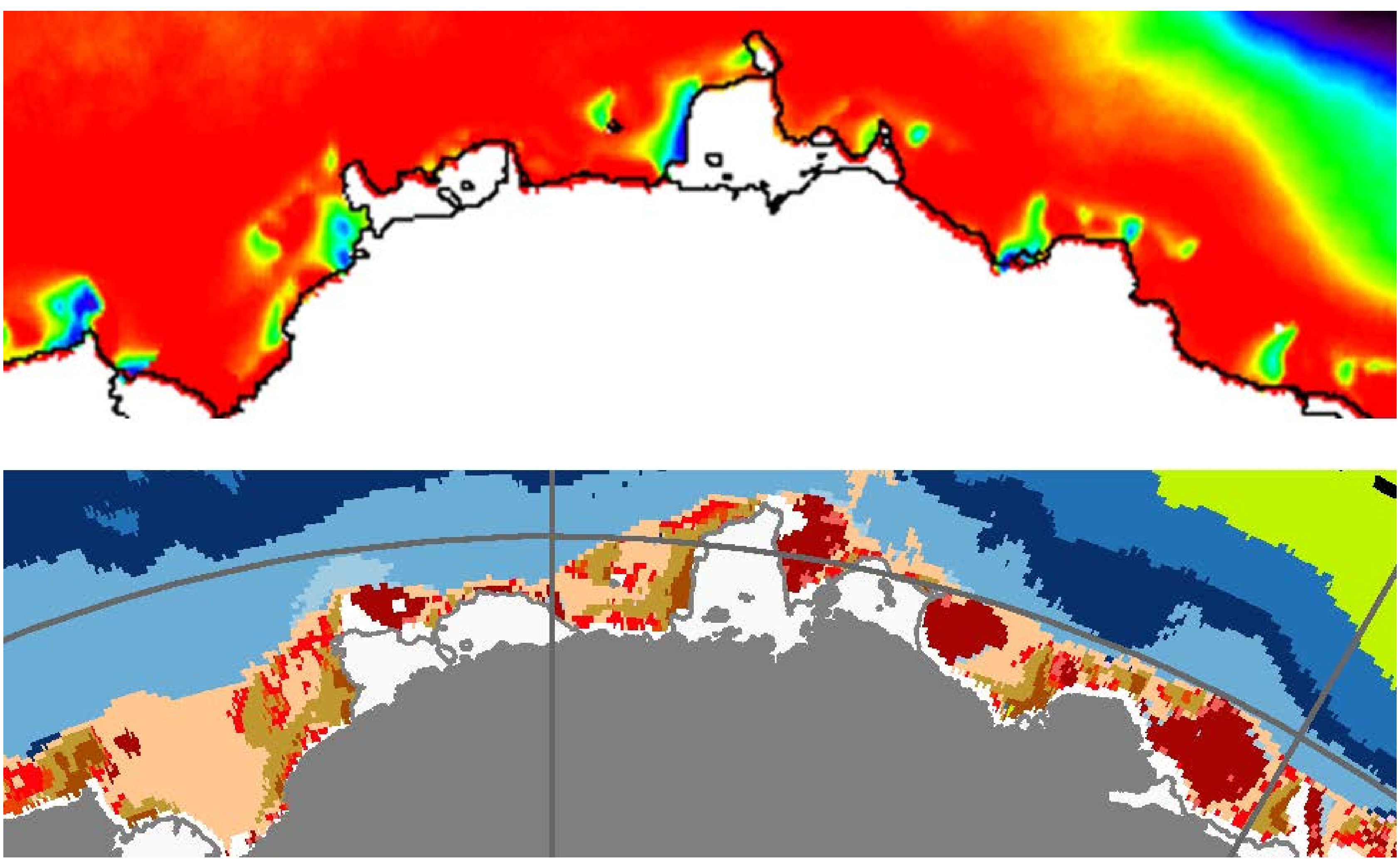


Figure 2 Properties of the 20 cluster types.



Pelagic Regionalisation Map 2 Locations of polynyas in East Antarctica (top; reproduced from Arrigo & van Dijken 2003). Clusters 1 and 2 (brown) show good correspondence with these locations (bottom).

4. Discussion

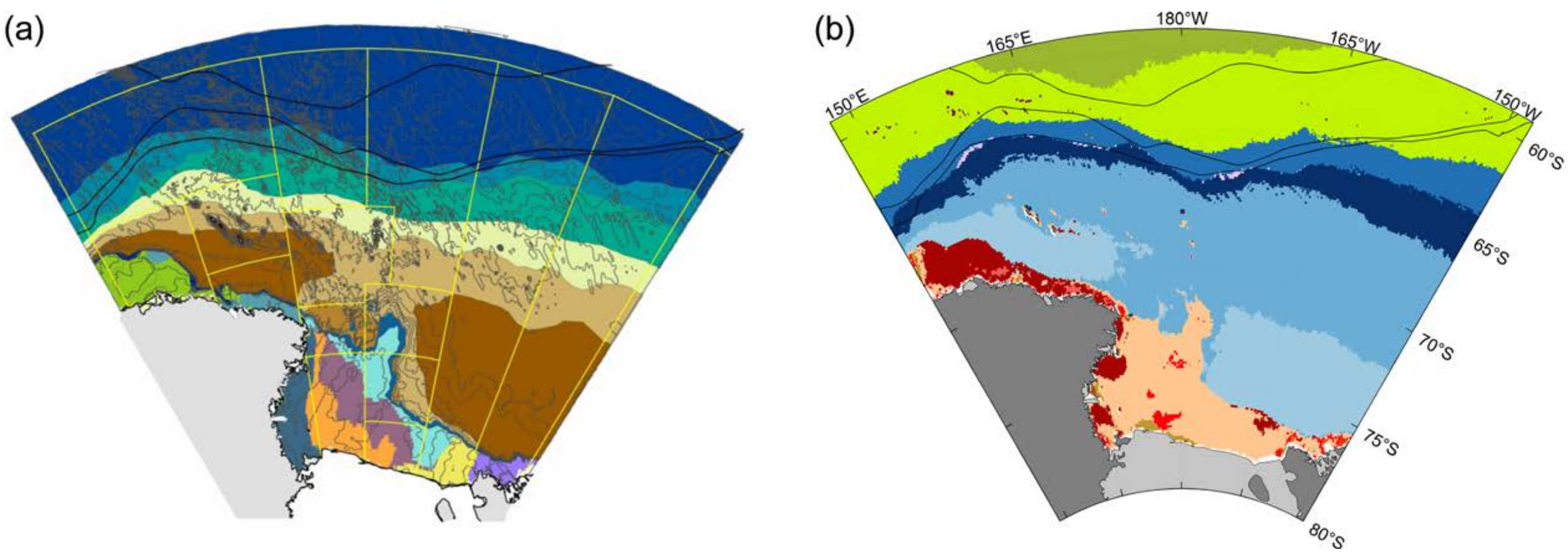
The results of these analyses are broadly similar to the 2006 primary regionalisation, with roughly concentric bands in open ocean areas, corresponding to the Southern Ocean fronts, and increased heterogeneity in shallower and near-coastal areas. The open ocean banding differs in detail between the two analyses. These differences are due in part to the different SST data sets used (1985–1997 Pathfinder data for the 2006 analyses, and 2002–2010 MODIS Aqua data here), as well as the fact that the open ocean regions experience no sea ice cover. Thus, cluster patterns in these areas in the current analyses are driven solely by differences in depth and SST. Previously, the sub-surface nutrient data would also have contributed to the open ocean structure. The Weddell Gyre, which was previously driven strongly by patterns in nutrient data, is now much less apparent.

The current results show an increased level of detail in shallow and near-coastal areas, because subsurface nutrient data (missing in many near coastal areas) were replaced by sea ice data, providing previously-missing spatial structure, particularly over the continental shelf. Previously, the Antarctic shelves were represented by a single class. These regions now have considerable additional substructure (i.e. clusters 1–7). The clusters representing polynyas (1 and 2; see examples in Map 2) show spatial distributions closely resembling the polynyas of Arrigo & van Dijken (2003).

The previous Kerguelen, Heard and McDonald Islands cluster is similar to the current cluster 13, which is now accompanied by a neighbouring class representing deeper areas of these plateaus (14). The previous Chatham Rise and Inner Shelf classes are still present, but merged into cluster 20. The Campbell Plateau and South American shelf class here (19) is largely identical to its 2006 counterpart.

A number of regionalisation analyses at smaller scales have recently been conducted (e.g. Constable *et al.* 2010, Sharp *et al.* 2010, Koubbi *et al.* 2011). Such regional-scale analyses are able to address smaller-scale structure and processes than a circumpolar analysis, and can make use of data with regional coverage that would be extremely difficult to include at a circumpolar scale. Thus, the general patterns in the current results should be similar to those derived at regional scales, but finer-scale details will likely differ.

The pelagic regionalisation of the Ross Sea region conducted by Sharp *et al.* (2010) is shown in Map 3a, with the matching subset of the current results shown alongside. The fine-scale regional analyses separated the continental shelf and off-shelf areas and conducted independent classification analyses for the two areas (Sharp *et al.* 2010). Analyses were based on water temperature, salinity, depth, and sea ice information, and identified 18 bioregions. Despite the differences in variables and spatial scale, the results from the circumpolar analyses are broadly similar, with a clear distinction between the shelf and offshore areas.



Pelagic Regionalisation Map 3 (a) Pelagic regionalisation of the Ross Sea region from Sharp *et al.* (2010). (b) Subset of the current results, for the same region. Black lines show (from north to south) the Polar Front, the southern Antarctic Circumpolar Current front, and the southern boundary of the ACC, as defined by Orsi *et al.* (1995). Yellow lines in (a) show CCAMLR small scale research units.

Acknowledgments

This is CAML contribution # 150.

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