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1 Improved bathymetry leads to >4,000 new seamount predictions in 2 the global ocean – but beware of phantom seamounts!

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11 **Abstract.** Seamounts are important marine habitats that are hotspots of species diversity. Relatively shallow peaks, increased
12 productivity and offshore locations make seamounts vulnerable to human impact and difficult to protect. Present estimates of
13 seamount numbers vary from anywhere between 10,000 to more than 60,000. Seamount locations can be estimated by
14 extracting large, cone-like features from bathymetry grids (based on criteria of size and shape). These predicted seamounts
15 are a useful reference for marine researchers and can help direct exploratory surveys. However, these predictions are
16 dependent on the quality of the surveys underpinning the bathymetry. Historically, quality has been patchy, but is improving
17 as mapping efforts step up towards the target of complete seabed coverage by 2030.

18 This study presents an update of seamount predictions based on SRTM30 PLUS global bathymetry version 11 and examine a
19 potential source of error in these predictions. This update was prompted by a seamount survey in the British Indian Ocean
20 Territory in 2016, where locations of two putative seamounts were visited. These ‘seamounts’ were targeted based on
21 previous predictions, but these features were not detected during echosounder surveys. An examination of UK hydrographic
22 office navigational (Admiralty) charts for the area showed that the summits of these putative features had soundings
23 reporting “no bottom detected at this depth” where “this depth” was similar to the seabed reported from the bathymetry
24 grids: we suspect that these features likely resulted from an initial misreading of the charts. We show that 15 phantom
25 seamount features, derived from a misinterpretation of no-bottom sounding data, persist in current global bathymetry grids
26 and updated seamount predictions. Overall, we predict 37,889 seamounts, an increase of 4,437 from the previous predictions
27 derived from an older global bathymetry grid (SRTM30 PLUS v. 6). This increase is due to greater detail in newer
28 bathymetry grids as acoustic mapping of the seabed expands.

29 The new seamount predictions are available at <https://doi.pangaea.de/10.1594/PANGAEA.921688>.

30 **Keywords**

31 Seamounts; Knolls; Bathymetry

32 **Introduction**

33 Seamounts are 'undersea mountains', and although many definitions of this term have been used, they are commonly
34 described as conical features that rise more than 1,000m above the surrounding seabed (IHO 2008). Seamounts are important
35 marine habitats, they provide a pathway for localized production (Hosegood et al., 2019), often increasing surrounding
36 biomass and species diversity (Letessier et al., 2017), they can be hotspots of predator biodiversity in the open ocean
37 (Morato et al., 2010), home to habitat-engineering species such as cold water corals (Tracey et al., 2011), important
38 spawning grounds (Tsukamoto, 2006), and even act as refugia from ocean acidification for carbon-calcifying species
39 (Tittensor et al., 2010).

40 The increased productivity associated with seamounts makes them attractive targets for fishing. Fishing gear can cause long-
41 lasting damage to habitat forming organisms associated with some seamounts (Althaus et al., 2009). Other threats to
42 seamounts include deep-sea mining and climate change, with shallower, more accessible seamounts at greater threat.
43 Protection of seamount habitats is a priority for marine conservation (Morato et al., 2010), but our knowledge on these
44 habitats remains limited, with estimates of only 0.4-4% of seamounts having been directly surveyed (Kvile et al., 2014).

45 Direct surveys require significant investment of resources and planning, and fundamental to this is identification of locations
46 of interest for the survey. However, we do not yet know how exactly many seamounts there are, with estimates ranging from
47 the tens to hundreds of thousands (Yesson et al., 2011). This has led to the publication of many predictive maps and
48 databases of potential seamount locations, commonly based on pattern recognition of underlying bathymetry data (Yesson et
49 al., 2011; Harris et al., 2014; Kitchingman & Lai, 2004), but also using satellite altimetry to detect larger features (Wessel,
50 Sandwell, and Kim 2010; Kim and Wessel, 2011).

51 Seamount predictive maps are dependent on the underlying data to extract features. Global bathymetry grids such as GEBCO
52 (General Bathymetric Chart of the Oceans - Weatherall et al., 2015) and SRTM (Shuttle Radar Topography Mission - Becker
53 et al., 2009) are models based on a combination of soundings (i.e. high resolution acoustic surveys) and satellite altimetry
54 (lower resolution data from satellite sensors). Satellite altimetry provides global coverage and is the foundation of
55 bathymetry models, but these sensors cannot determine small features (i.e. seamounts under 1.5km height, Wessel et al.,
56 2010). Acoustic surveys generate data best suited for determining seabed depth and these are utilised to constrain models
57 used to create bathymetry grids (Becker et al., 2009). Despite global efforts to improve coverage, such as the Nippon
58 Foundation-GEBCO challenge to survey the ocean floor across the globe by 2030 (Wöflfl et al., 2019), soundings in the latest
59 bathymetry grids are limited to a small proportion of the ocean, and the majority of bathymetry grid data is derived from the
60 underlying model rather than acoustically surveyed. For example, only 18% of current GEBCO grid cells (each 30x30 arc
61 seconds \approx 1x1km at the equator) are directly supported by acoustic surveys (Weatherall et al., 2015). Since sounding data is
62 limited, it is valuable to make use of all available data. Historical soundings based on weighted lines have been extracted
63 from nautical charts to expand the data available (Becker et al., 2009).

64 This study describes issues with seamount predictions stemming from the use of historical sounding records, based on the
65 findings of a seamount survey in the Indian Ocean. It presents an update of previous seamount predictions and examines
66 whether this erroneous use of historical data persists.

67 **BIOT Seamount Survey**

68 The British Indian Ocean Territory (BIOT) is a region of the Indian Ocean encompassing a variety of undersea features,
69 including the flat shallow banks of the Chagos Archipelago, and the high slopes of the Chagos-Laccadives ridge, and depths
70 beyond 5,000m (Sheppard et al., 2012). The area could be home to as many as 86 seamounts, based on estimates from an
71 automated seamount-recognition algorithm applied to version 6 of the SRTM30 PLUS global bathymetry grid (Yesson et al.,
72 2011). Two of these predicted seamounts, clearly discernible on the latest bathymetry grids, were targeted during a 2016
73 multidisciplinary survey around the Chagos Archipelago (Letessier et al., 2016). The seamount section of the survey moved
74 around the Great Chagos bank spanning c.5-7°S and 71-73°E, between 5-24th February. Two seamounts of interest were ID
75 4050548 (latitude -5.354, longitude 71.292, summit depth 481m) and ID 4060551 (lat. -5.733, long. 71.396, depth 141m)
76 from Yesson et al., (2011). The survey sought to visit these features for the purpose of establishing baseline monitoring sites
77 for mobile oceanic predators (Letessier, Bouchet, and Meeuwig 2017). Seamounts in BIOT have previously been shown to
78 be important location of bio-physical coupling between reef and pelagic ecosystems, and may therefore support elevated
79 numbers of predators (Hosegood et al., 2019; Letessier et al., 2016; Letessier et al., 2019). Acoustic data were collected
80 using a Simrad (Bergen, Norway) EK60 echosounder operating at 38 kHz with a pulse length of 1.024ms and ping rate of 2s.
81 At these settings, the seabed was detectable up to 1,500m below the surface. Seabed was detected at around this depth for
82 seamount A (predicted depth 183m), but no seabed was detected around the area of seamount B (predicted depth 491m)
83 despite circling (up to 5km) around the supposed summits (Fig. 1 & 2). We note that the source of the reading that accounts
84 for seamount B was a digital nautical chart from the National Geospatial Agency and this erroneous point is removed from
85 construction of more recent bathymetry grids (D. Sandwell pers. comm.).

86

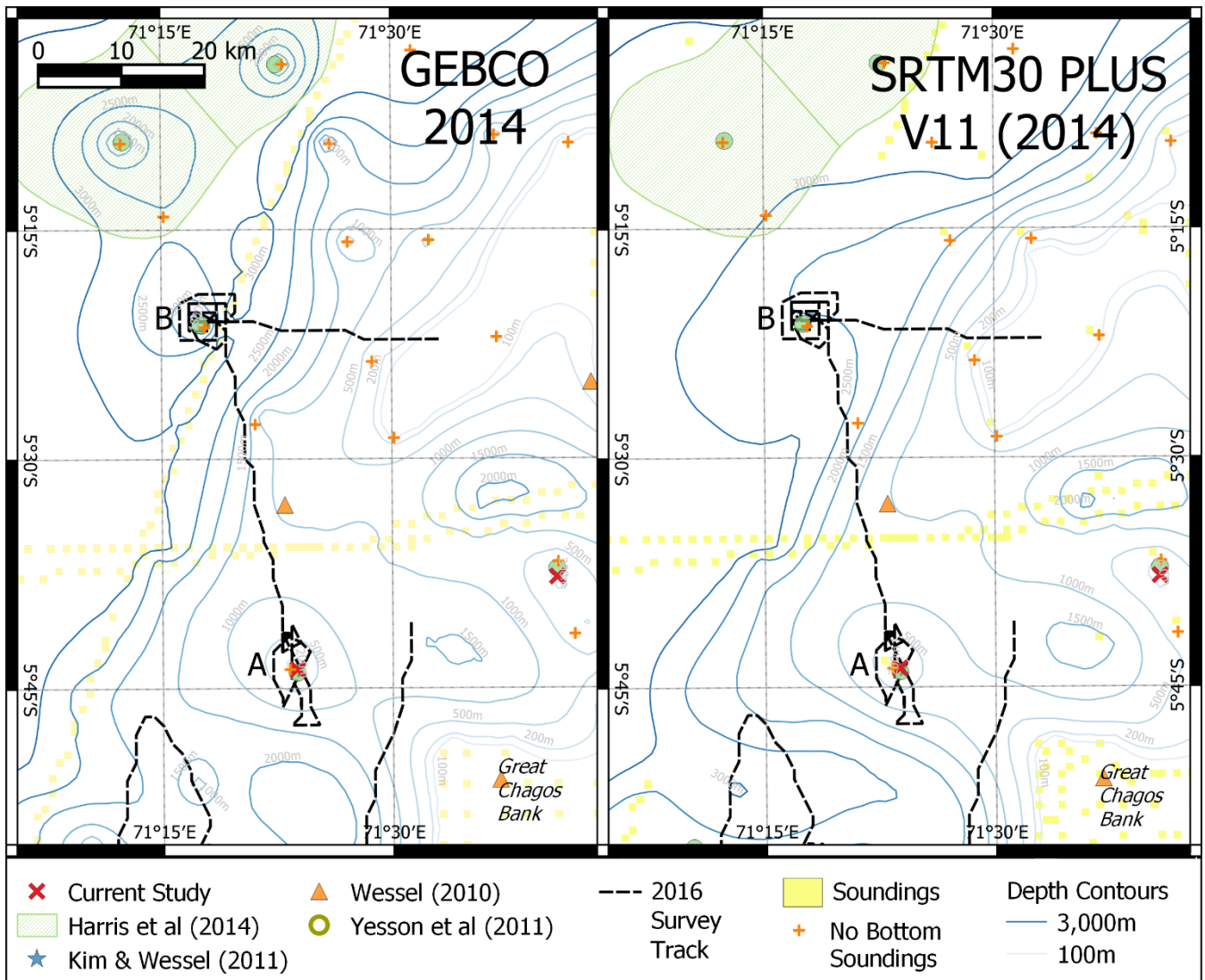
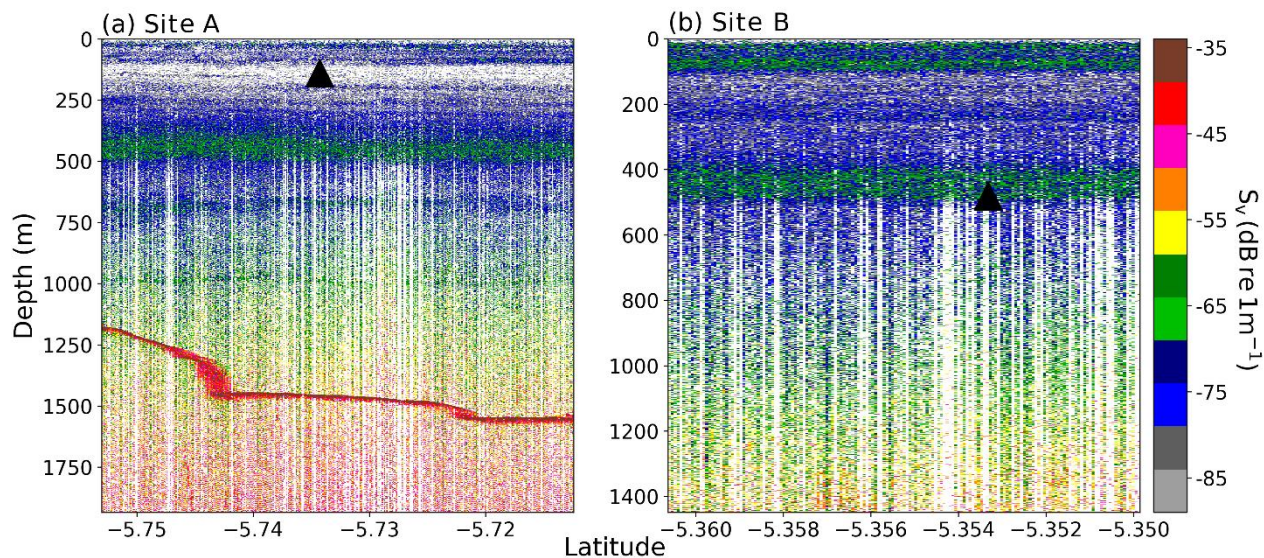


Figure 1: Location of survey conducted in 2016. Left shows depth contours based on the 2014 GEBCO bathymetry grid, right shows depth contours derived from SRTM30 PLUS v11. Both grids indicate the presence of a conical seamount (A) c.20km NW of the Great Chagos Bank. No feature was detected by the 2016 survey. Around 40km north of this, is another predicted seamount (B), again not detected on the 2016 survey. Feature B is predicted by the GEBCO grid, but is not shown in the SRTM30 plus grid (although present in previous versions). Map projection UTM zone 43 south (epsg:32743).



93

94 **Figure 2: Latitudinal transects across apparent positions of the two phantom seamounts. Black triangles are overlaid at the**
 95 **position and summit depth of the predicted seamounts. Colormap is Volume Backscattering Strength (S_v). A deep scattering layer**
 96 **was observed at c.450m for both sites. Seabed was observed at site A c.1,500m (red line). No seabed was detected for site B (i.e.**
 97 **seabed is deeper than the limit of the sensor).**

98 An examination of the admiralty chart for the region provided some insight. Soundings on charts are recorded by displaying
 99 the depth reading over the location. A different class of sounding is also recorded. Soundings where no bottom was recorded
 100 are annotated with $\frac{\text{---}}{\text{Depth}}$ at the location of the sounding. These soundings are typically old, prior to the nineteenth century,
 101 dating from when soundings were conducted using handheld, weighted, lead lines, before the widespread use of sounding
 102 machines. It is easy to mistake these as bottom soundings, and this appears to be the root cause of the 'phantom seamounts'.
 103 For site A (Fig. 1) there is a sounding in the chart at the summit of the mound seen on the bathymetry grids. The chart
 104 reports no bottom recorded at 183m, while the GEBCO depth at this cell is 179m and SRTM30 plus depth is 183m.
 105 However, the SRTM30 plus grid at site B does not show a seamount-like feature, in contrast to GEBCO, which shows an
 106 isolated point of markedly higher elevation, which is interpreted as a conical seamount-like peak by seamount detection
 107 algorithms. It is noted that previous versions of the SRTM30 plus grid showed a seamount-like feature at this location. The
 108 version history reports the removal of isolated and outlier "bad pings" prior to the construction of version 11. The revision of
 109 SRTM has removed other seamount-like features from the revised bathymetry grid (i.e. NW corner of Fig. 1). It is apparent
 110 that bathymetry grids such as GEBCO and SRTM30 plus have mistakenly used these "no seabed detected" observations as
 111 soundings indicating seabed depth, and in regions with sparse sounding data, these spatially isolated erroneously interpreted
 112 records are sufficient to create a local maxima that creates the appearance of a seamount in the final bathymetry grid.
 113 This study aims to update the Yesson et al., (2011) seamount predictions using the latest available bathymetry and assess the
 114 impact of no bottom sounding data on the prediction of seamounts.

116 **Methods**

117 Version 11 of the Shuttle Radar Topography Mission “SRTM30 PLUS” global bathymetry (Becker et al., 2009 – version 11
118 released 2014) was used to update the seamount prediction estimates of Yesson et al., (2011). The prediction algorithm of
119 Yesson et al. (2011), which identifies seamounts as cone-shaped features rising more than 1000m above the surrounding
120 seabed, was run on SRTM30 plus V11, creating a new set of seamount predictions based solely on the new bathymetry .

121 New seamount predictions were compared with the previous dataset (Yesson et al., 2011 – henceforward the ‘old’ dataset).
122 Seamounts were defined as present in the old dataset if the base of a seamount in the new dataset spatially overlapped with a
123 seamount summit in the old seamount dataset (i.e. both datasets have a predicted seamount in approximately the same
124 location). Seamount bases are the area covered by the ‘cone’ of the seamount, and are delimited by 8 radii 45° apart,
125 radiating from the seamount summit point, that extend outwards from this point until the downward slope levels off, up to a
126 maximum distance of 20km from the summit (thus the maximum base area is ~1,131 km²). These seamount bases can, and
127 often do, encompass multiple seamount peaks in both the old and new datasets, but a new seamount has to overlap with just
128 one seamount in the old dataset to count as being a consistent prediction.

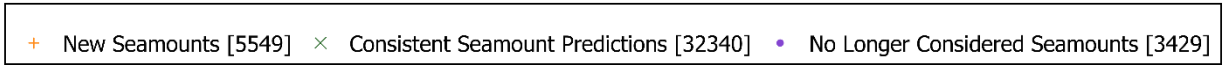
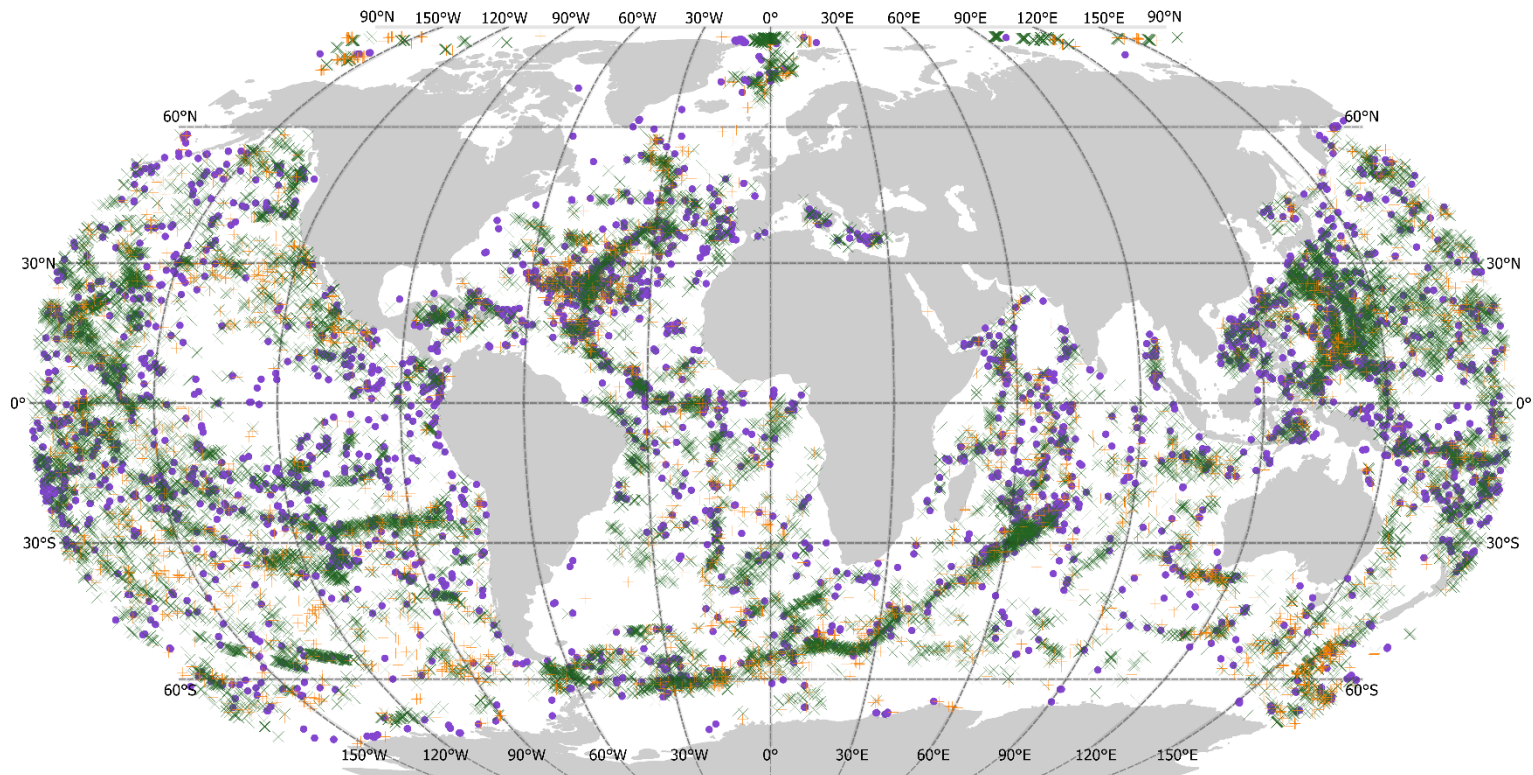
129 A dataset of ‘no bottom sounding’ observations was provided by Oceanwise Ltd, from a dataset of depth readings from
130 digitised admiralty charts. These data include 1,009 observations from charts covering the majority of the Atlantic and East
131 Pacific, but with little data from the Southwest Indian Ocean and West Pacific. The depth readings of no-bottom soundings
132 that were spatially located within seamount bases were compared with the summit depths, seamounts with peak-depth
133 similar to ‘no bottom sounding’ depths (+/-50m) were regarded as potential “phantom seamounts”.

134 **Results**

135 The updated seamount predictions based on the SRTM30 PLUS v11 bathymetry gives a total of is 37,889 seamounts. A map
136 of these is presented in Fig. 3. There are 32,340 ‘consistent’ seamounts in the new dataset that overlap with predictions from
137 Yesson et al., (2011) and 5,549 ‘new seamounts’ (15%) that do not overlap with old predictions. Conversely, there are 3,429
138 seamount predictions in the old dataset (=10% of old seamount predictions) that do not overlap with the seamount bases of
139 the new dataset.

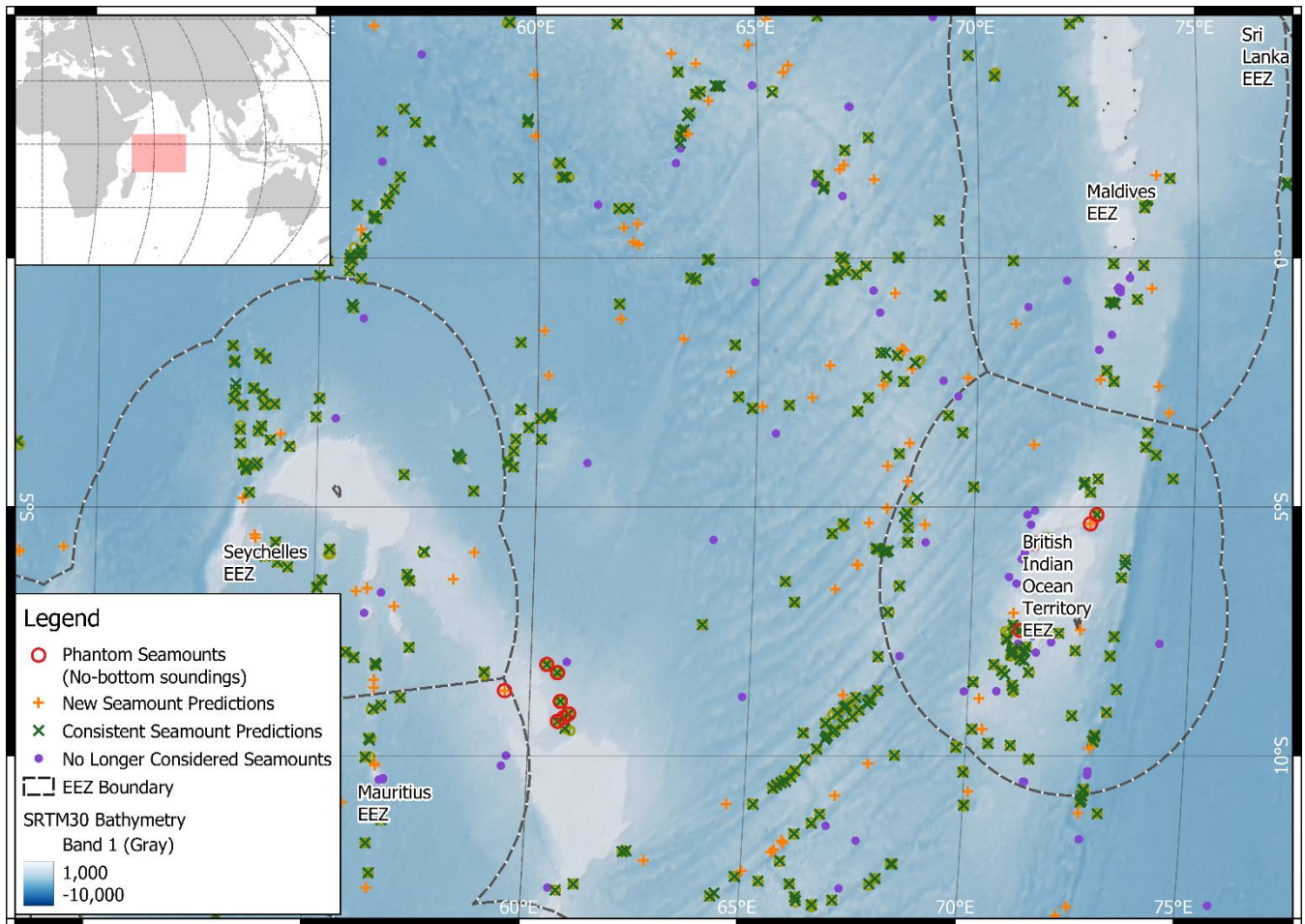
140 There are only 15 seamounts in the new dataset that fit a “phantom seamount” profile (i.e. near a ‘no bottom sounding’
141 record with the seamount peak of similar depth to the sounding record), these are presented in Table 1. In contrast there are
142 14 seamounts from the ‘old’ 2011 dataset that fit this pattern. These “phantom seamounts” are focused in the Indian Ocean
143 (12/14 from 2011 data and 12/15 from the updated dataset), with 4 potential phantom seamounts around Chagos Bank and 6
144 from the southern Mascarene Plateau (Fig. 4).

145 The “phantom” seamounts are all in shallow water (summit depth <1500m) and most are in the southern hemisphere (Fig. 5).
146 The majority of seamounts are at the smaller end of the size distribution and typically found at 2000-3000m depth (Fig 5).
147 However, the “new” seamounts from the 2019 data are overrepresented in the smaller and deeper categories, while the
148 seamounts only seen in the 2011 dataset are greatly focussed on the smallest size class.
149



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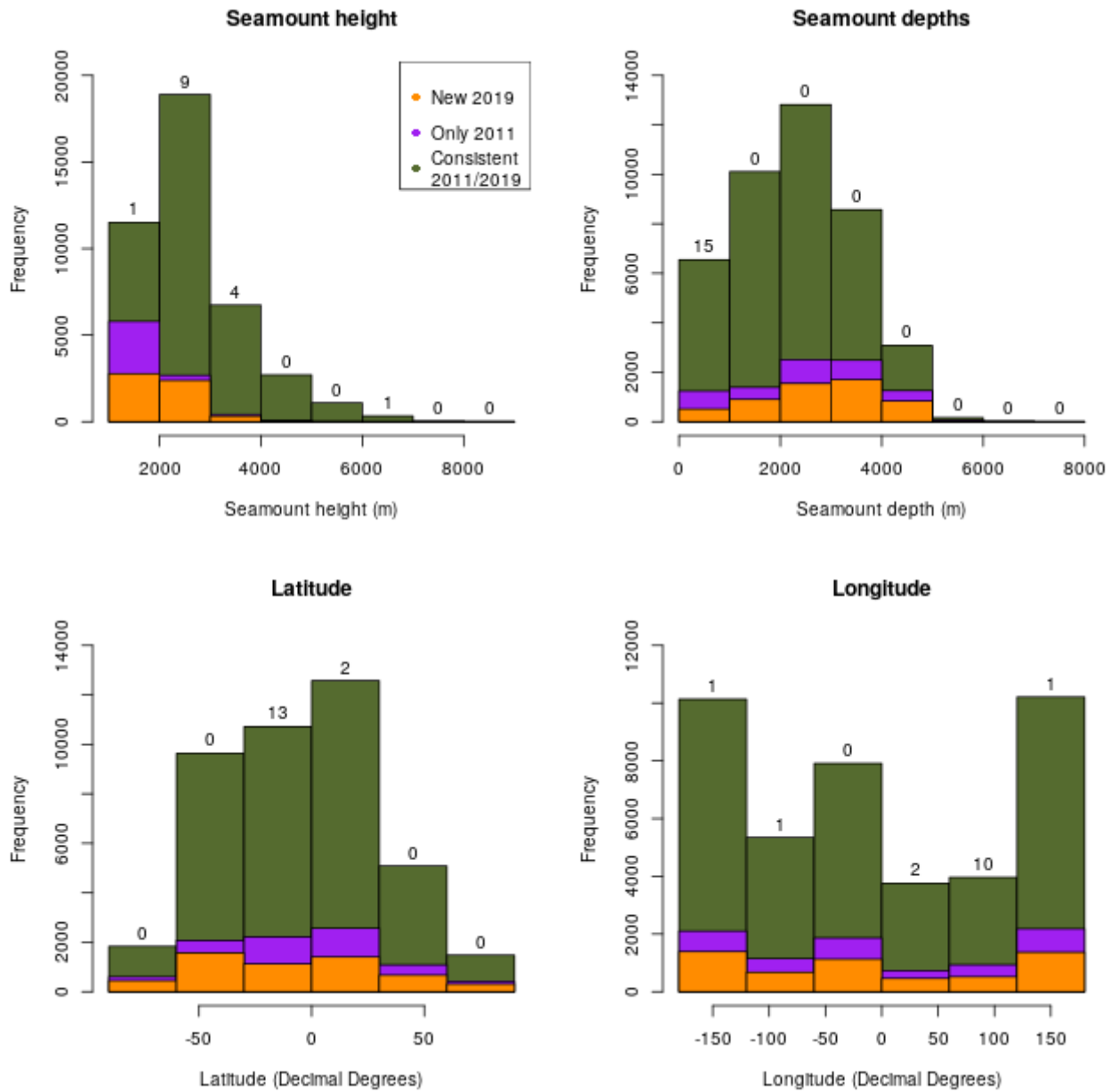
151 **Figure 3: Map of predicted seamounts. New Seamounts are those in the new dataset that are not found in the Yesson et al., (2011) dataset. “Consistent**
 152 **predictions” are new predictions that spatially overlap with the old predictions of Yesson et al., (2011), while those seamounts present in Yesson et al.,**
 153 **(2011) but with no overlapping feature in the updated dataset are classed “no longer considered seamounts”. Robinson map projection (EPSG:54030).**
 154 **Lat/Long grid lines at 30° intervals.**



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Figure 4: Focus on Seamounts of NW Indian Ocean. Most of the 15 predicted seamounts based on no-bottom soundings are in the Indian Ocean. Inset table (top left) shows the full list of 15 “phantoms.” EEZ are Exclusion Economic Zones (boundary of national jurisdiction – source <https://www.marinerregions.org/>). Robinson map projection (EPSG:54030). Lat/long lines shown for reference.

160



161

162 **Figure 5: Histograms showing distribution of seamounts by seamount height (top left), depth of seamount summit (top right), and**
 163 **geographic location of seamount (latitude – bottom left, longitude – bottom right). Numbers above the bars show the count of**
 164 **“phantom” seamounts in the relevant grouping.**

165

PeakID	Depth (m)	Height (m)	Longitude	Latitude
4509328	52	1,732	59.42083	-8.68750
4523965	2	2,015	60.79583	-9.22917
4525766	2	2,051	60.65417	-9.30417
4515124	65	2,114	60.70417	-8.90417
4475075	304	2,267	71.12917	-7.47917
4408881	191	2,354	72.78750	-5.15417
4521899	2	2,409	60.90417	-9.15417
4414134	135	2,481	72.64583	-5.33750
844462	166	2,712	71.39583	-5.72917
3736711	2	2,802	-65.93750	17.80417
888460	2	3,068	43.92083	-12.38750
4495055	54	3,676	60.36250	-8.16250
699884	133	3,752	144.38750	12.77917
4499613	85	3,762	60.61250	-8.32917
4264476	17	6,361	-159.97917	-0.37917

166

167 **Table 1. List of ‘phantom seamounts’ where inferred seamounts appear coincide with sites of ‘no bottom soundings’**

168 **Discussion**

169 The 37,889 seamounts predicted from the latest SRTM30 plus bathymetry represents an increase in number (4,437=13%) of
170 seamounts predicted from the previous study (N=33,452). The revised predictions are higher than other predictions that post-
171 date Yesson et al., (2011) such as 24,643 seamounts in the Kim & Wessel (2011) dataset and 10,234 of Harris et al (2014),
172 but it is still lower than some other predictions, e.g. 68,669 of Costello et al., (2010). It is worth noting that each of these
173 studies uses different ways of detecting seamounts, for example Harris et al., (2014) have a stricter definition of seamount
174 that excludes features along ridges, while the methodology used in this study (from Yesson et al., 2011) employs a distance-
175 based filtering of adjacent features.

176 Regardless of the methodology used, it is important to keep prediction datasets up-to-date with the latest bathymetry grids.
177 We note that a global 15 second bathymetry grid is available (SRTM15+ v2.1, Tozer et al., 2019), and that this greater detail
178 may assist with seamount identification, although may require adjustment of the current methodology to fully utilise (Yesson
179 et al., 2011). We expect the expansion of multibeam echosounder data (Wöflfl et al., 2019) to allow the detection of smaller
180 (<1.5km) features in regions where previously bathymetry grids relied on only coarse resolution satellite-derived data, which

181 is why authors have extrapolated their ‘detected’ seamount numbers to higher global estimates (e.g. Kim & Wessel, 2011
182 detect 24,643 seamounts, but extrapolate this to a global total of 40,000-55,000). This pattern of increased seamount
183 detection as more acoustic data becomes available fits our observation and we note that the majority of “new” seamounts are
184 in the smaller, deeper size and depth categories, which is consistent with greater acoustic data giving more detailed
185 resolution. We also note that these totals are really counts of seamount peaks, some of which may be linked together into
186 seamount chains which could be regarded as a single feature. This potential double-counting may become more prevalent as
187 these features are mapped in greater detail and smaller peaks on larger structures are identified. It was to address this issue
188 that Yesson et al. (2011) introduced an optional filter to remove spatially adjacent features, and we recommend always
189 examining the filtered and unfiltered predictions with this in mind.

190 However, there is a competing pressure that may lead to a reduction of seamount numbers, as isolated ‘no bottom soundings’
191 or erroneous readings, such as those identified in this study, are removed from bathymetry grid construction, so features
192 defined by these mistakes should be removed as underlying grids are improved (Becker et al., 2009; Weatherall et al., 2015).
193 It is imperative that our predictions are as accurate as possible, as every erroneously identified feature could prove costly in
194 terms of the investment required to conduct a research cruise to a “phantom seamount” or the negative effects of taking
195 protection measures for non-existent features. Fortunately, the scale of the problem directly identified in this study appears to
196 be small and will likely reduce as methods improve and primary data collection expands. However, not all of these ‘no
197 bottom sounding’ records have been removed and there may be other causes of error not currently identified.

198 Finally, although these predictions are based on a global bathymetry grid, we note that seamount predictions based on the
199 lat-long bathymetry grid perform poorly at high latitudes where there is a large spatial distortion. Seamount predictions for
200 Arctic and Antarctic regions should be remade based on polar specific grids such as the International Bathymetric Chart of
201 the Arctic Ocean (IBCAO - Jakobsson et al., 2012).

202 **Conclusion**

203 Bathymetry grids are continually improving (Wöfl et al., 2019), whether that is from new multibeam acquisition, such as
204 that collected during the search for Malaysian Airlines flight MH370 (Smith and Marks 2014), or improved satellite gravity

205 data (Sandwell et al., 2014). However, these bathymetry grids still rely on sparse sounding data for many regions, and thus
206 have the capacity to mislead if invalid historical weighted line measurements are used in the construction of bathymetric
207 models as isolated falsely interpreted records can lead to the appearance of “phantom seamounts.” Despite advances in data
208 acquisition, modelling and prediction methods, these data will continue to contain errors. Therefore, it is important that we
209 use all the information available, including multiple seamount predictions, multiple bathymetry models and printed charts to
210 assess potential seamount distributions, particularly when planning surveys to unsampled seamounts, or in the arena of
211 conservation planning, where seamount distributions can be used as proxies for endangered predator distributions (Bouchet
212 et al., 2014).

213 **Data availability**

214 Updated seamount predictions are available to download at (<https://doi.pangaea.de/10.1594/PANGAEA.921688>).

215 **Author contribution**

216 CY & TL conceived the work. TL, ANS, PH, AB & RP planned and conducted fieldwork. CY, TL & MH assembled the
217 data. CY performed analysis. All contributed to writing.

218 **Competing interests**

219 The authors declare that they have no conflict of interest.

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