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A review of the influence of marine habitat classification schemes on mapping studies: inherent assumptions, influence on end products and suggestions for future developments

James Asa Strong[1], Annika Clements[2], Helen Lillis[3], Ibon Galparsoro[4], Tim Bildstein[5], Roland Pesch[5]

Affiliations

1 National Oceanography Centre, European Way, Southampton, SO14 3ZH, UK. Corresponding author. Email: james.strong@noc.ac.uk

2 Fisheries and Aquatic Ecosystems Branch, Agri-Food and Biosciences Institute, 18a Newforge Lane, Belfast, BT9 5PX, UK

3 Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough PE1 1JY, UK

4 AZTI-Tecnalia, Marine Research Division, Herrera Kaia Portualdea z/g, 20110 Pasaia, Spain

5 BioConsult Schuchardt & Scholle Gbr, Reeder-Bischoff-Str. 54, 28757 Bremen, Germany

19 **Abstract**

20 The production of marine habitat maps typically relies on the use of Habitat Classification

21 Schemes (HCSs). The choice of which HCS to use for a mapping study is often related to

22 familiarity, established practice, and national desires. Despite a superficial similarity, HCS

23 differ greatly across six key properties, namely, purpose, environmental and ecological scope,

24 spatial scale, thematic resolution, structure and compatibility with mapping techniques. These

25 properties impart specific strengths and weaknesses for each HCS, which are subsequently

26 transferred to the habitat maps applying these schemes. This review has examined seven

27 common HCSs, over the six properties, to understand their influence on marine habitat

28 mapping. Recommendations are provided for improving HCSs for marine habitat mapping as

29 well as for enhanced the working practices of mappers using habitat classification. It is hoped

30 that implementation of these recommendations will lead to greater certainty and usage within

31 mapping studies and more consistency between studies and adjoining maps. A review of six

32 common HCSs has been conducted to highlight these issues, and to raise awareness of how

33 these properties and assumptions are transferred into marine habitat maps. In addition, how

34 mappers use HCSs also introduces additional uncertainties and biases into the final maps.

35 **Keywords**

36 Marine habitat mapping; habitat classification scheme;

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2

1. Introduction

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40 The pressing need for seabed inventory mapping, marine spatial planning, spatial estimates of

41 anthropogenic impacts (as required by the Marine Strategy Framework Directive (Council

42 Directive 2008/56/EC)) and the designation of seabed conservation features (as required by

43 the Habitats Directive 92/43/EEC) has made the habitat map an indispensable item within

44 marine management and research. The production, and ultimate presentation, of marine

45 habitat maps typically rely on the use of a habitat classification scheme (HCS). Within

46 mapping, HCSs categorise environmental and biological information (e.g., depth,

47 topography, substratum, hydrodynamic energy, community composition) into distinct habitat

48 classes. Each class is assumed to be associated with a distinctive abiotic condition and

49 identifiable biological community, and therefore attempts to produce environmentally or

50 ecologically meaningful units.

51 Habitat classification is an integral part of habitat map production, and as such, the HCS has a

52 significant influence on how mapping information is: (i) interpreted during map production;

53 (ii) displayed within the map; and (iii) interpreted by the end user. This review aims to

54 examine explicitly how HCSs influence the production of marine habitat maps. A wider

55 discussion will follow on what improvements can be made to HCSs, and how mappers should

56 use these HCSs, to provide more consistent, accurate and useful products for end users. The

57 specific objectives of this review are:

58   1. Introduce the principles of habitat classification for marine mapping;

59   2. Describe the properties common to most HCS;

60   3. Examine the variation in these common properties for seven, established HCSs,

61   used for benthic habitat mapping;

4. Assess the influence of variations within these common properties on the production and representations of marine habitat maps;

5. Make recommendations for the development of HCSs in habitat mapping; and

6. Recommend best practice for marine habitat mappers when using HCSs.

2. Use of habitat classification schemes in marine mapping

Although HCSs are developed to support all sorts of environmental work, few activities are as intimately linked to the use of HCSs as habitat mapping. Many HCSs have been developed specifically for use in mapping studies, e.g., Potential Habitat Characterization Scheme (PHCS, Greene et al. 2005, 2007). This section introduces HCSs, as well as how and why they are incorporated into marine habitat mapping. The influence that HCSs have on habitat maps is also introduced, before being discussed in more detail at the end of the review.

2.1. Habitat classification schemes

Robinson and Levings (1995) defined a HCS as a set of instructions that identify, delimit and describe the habitats of distinct biological assemblages (communities or single species). The primary purposes of HCSs, summarised from Galparsoro et al. (2012) and Robinson and Levings (1995), are to:

• provide a structured framework for the efficient classification of habitats;

• provide common and easily understood concepts and language for the description of habitats;

• hold information in a relational structure that allows for the interrogation of information based on parameters collected by common survey methods;

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85   • describe and standardise the physical, chemical and biological parameters that define

86   habitat classes; and

87   • regulate the spatial and thematic scales and thresholds used for habitat classification,

88   and thereby standardise the classification of habitats within and between studies.

89   The use of a HCS benefits marine habitat mapping in several ways. Most importantly, the

90   HCS provides a structured framework for the integration of environmental and biological

91   information (which have different spatial scales, units, and formats) into one, integrated

92   product, via ecologically meaningful decision points along the classification pathway.

93   Ultimately, HCSs facilitate the segmentation of discrete (e.g., categorical data such as

94   substratum) and continuous variables into ecologically relevant spatial units.

95

96   2.2. **The influence of habitat classification schemes on the outputs of habitat**

97   **mapping**

98   Although the benefits associated with the consistent classification of habitats during mapping

99   are great, it must also be recognised that the use of a HCS also imposes certain constraints

100   and limitations, which are inherent within the fundamental concepts of habitat classification.

101   For example, many HCSs assume that individual habitats are discrete classes. When used in

102   mapping, these classes form mutually exclusive patches when presented spatially, and

103   therefore fail to capture the natural continuities (biocoenoses) and environmental gradients

104   (ecotones) that perhaps better reflect the natural configuration and gradients between

105   different habitat types.

106   The structure of an HCS has a marked effect on the production process for a habitat map,

107   through dictating when different types of information are relevant during the classification

108   pathway. The structure can, therefore, modify the relative importance of physical, chemical

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109   and biological variables in determining the final classification for a unit of habitat. The

110   physical information is typically associated with the upper levels of the hierarchy and can

111   sometimes be assigned based on existing, coarse-resolution data such as from hydrodynamic

112   models and digital elevation models. Lower levels of classification (biotopes, communities

113   and single-species distribution) often require biological data and are often applied at a more

114   local scale. Due to insufficient biological data, or because it is not relevant for the specific

115   scheme or level of classification, some HCSs are based purely on physical and environmental

116   features of the seafloor environment, which are used as a proxy for habitats, on the

117   assumption that there may be a correlation between the non-biological features and biological

118   communities (Brown et al., 2011; Huang et al., 2011). Such assumptions are the basis for the

119   use of distribution modelling techniques by employing full spatial coverage data of

120   environmental variables to predict benthic spatial distribution patterns during the map

121   production (Reiss et al., 2014).

122   Although it is a sensible aspiration that a single classification scheme is used for all marine

123   habitat maps, multiple schemes have arisen to cater for the different applications, e.g.,

124   biological conservation, landscape ecology, environmental monitoring, marine spatial

125   planning, fisheries management, and geomorphological descriptions, etc. The presence of

126   several HCSs also reflects the fundamental difficulty of dividing natural continuities

127   (biocoenoses) and environmental gradients (ecotones), into discrete and meaningful classes

128   (McDougall et al., 2007). Furthermore, the number of HCSs is further inflated as individual

129   schemes cater for specific biogeographic areas. Lund and Wibur (2007) and Greene *et al*.

130   (2008) summarised 14 marine HCSs developed for North America and Europe alone.

131   Interestingly, schemes differ substantially even though (i) the main physico-chemical

132   variables that are known to define habitats are well-established, (ii) the majority of marine

133   mapping studies record the same parameters and (iii) the predominantly physical nature of

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134   the majority of the classifications. The use of different HCSs for mapping can significantly

135   influence the spatial representation of habitats in the final maps, which in turn can hinder the

136   merging of adjoining maps as well as alter management outcomes based on these maps.

137

138   2.3. **Variation and influence associated with six common properties of marine**

139   **habitat classification schemes**

140   An examination of the HCS suggests that they differ according to six properties, namely: (i)

141   purpose of a HCS; (ii) environmental and ecological scope of a HCS; (iii) spatial scale

142   covered by a HCS; (iv) thematic resolution covered by a HCS; (v) structure of a HCS; and

143   (vi) compatibility of a HCS for habitat mapping. Variation in each property can influence the

144   production, and representation, of a marine habitat map. The following section will: (i)

145   introduce each property; (ii) examine seven common HCSs to highlight the variation within

146   each property (these schemes are introduced in Table 1); and (iii) summarise the influence of

147   variation, within each property, on habitat map production.

148   **2.3.1. The purpose of a habitat classification scheme**

149   A number of HCSs have been constructed for differing but specific purposes. For example,

150   some schemes are designed to address the delineation of fisheries habitats, while others

151   specifically include habitats of conservation importance. Most schemes are more generic

152   classifications, which are more suitable for inventory mapping. The purpose of a HCS

153   dictates the emphasis for separation between classes, and therefore the way in which

154   observed variables are partitioned within the scheme. This structuring is reproduced within a

155   habitat map when a specific HCS is used.

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Variation in the purpose between habitat classification schemes

157 The majority of HCSs are generalist, descriptive schemes that potentially offer the greatest

158 utility to the largest number of users. Maps produced using these schemes are most likely to

159 be centrally collated and widely distributed. For instance, European policies, including the

160 Habitats Directive (92/43/EEC), the Marine Strategy Framework Directive (MSFD;

161 2008/56/EC), the Infrastructure for Spatial Information in the European Community

162 (INSPIRE; 2007/2/EC), and the Maritime Spatial Planning (Directive 2014/89/EU), aimed at

163 marine mapping, assessment and reporting are increasingly using EUNIS and HELCOM

164 Underwater Biotopes (HUB) (within the Baltic Sea) habitat categories and respective codes

165 so as to guarantee a common shared path and technical terminology between Member States

166 (Vasquez et al., 2015).

167 The Australian National Intertidal/Subtidal Benthic (NISB) scheme (Mount et al., 2007) and

168 the Classification of Sublittoral Habitats (CSH) scheme (Valentine et al., 2005) are also broad

169 enough to allow full coverage mapping and use for the environmental management of

170 seafloor habitats (although NISB primarily focused on managing climate change related

171 issues), as well as specifically providing a foundation for scientific research.

172 The primary purpose of Coastal and Marine Ecological Classification Standard (CMECS) is

173 to be a national standard for the classification of habitats that ensures the consistency of state,

174 national and international outputs (Madden *et al*., 2005). Unlike other schemes, CMECS is

175 claimed to be relatively multipurpose in that it also caters for (i) fisheries management; (ii)

176 the identification and administration of marine protected areas (Madden *et al*., 2005); and (iii)

177 ecosystem-based management of marine resources. By contrast, the Potential Habitat

178 Characterization Scheme (PHCS: Greene *et al.* 1999, 2005, 2007) has a clear geological

179 emphasis, which is thought to provide a better basis for fisheries management, i.e., the

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180   identification of Essential Fish Habitat. Consequently, this scheme has been adopted for the

181   contiguous western coast of the USA for rockfish habitat mapping (Greene *et al.*, 2007).

182   Management purposes lie at the heart of the Hierarchical Framework of Marine Habitat

183   Classification for Ecosystem-Based Management (HFMHC: Guarinello *et al.*, 2010), which

184   has been specifically designed for promoting ecosystem-based management (Guarinello *et*

185   *al.*, 2010). The framework incorporates the central concepts of ecosystem-based management

186   - this ensures that the products of this HCS reflect the values and objectives of this style of

187   management. The HELCOM HUB scheme has also been designed to align with a strategic

188   plan to ensure ecosystem-based management (HELCOM Baltic Sea Action Plan) in the entire

189   Baltic Sea region (HELCOM, 2013).

190   *Summarising the influence of habitat classification scheme purpose on habitat maps*

191   The majority of HCS are generic, inventory schemes that have subsequently been adopted for

192   use in marine management. Several of the European systems were, however, designed

193   initially for the ready identification of habitats of conservation importance. Other schemes are

194   more specific, in either dealing with components of the habitat (e.g., ground fish), specific

195   management topics (e.g., climate change, fisheries, conservation, ecosystem-based

196   management). The purpose of an HCS will dictate the information that is required within the

197   classification and, ultimately, how this information is partitioned and presented within a map.

198   Most habitat mapping studies adopt just one HCS, and consequently limit the maps to a

199   specific set of purposes. This restricts both the breadth of the maps for other purposes and

200   how exhaustively the mapping data is used. It is likely that the greatest utility, accuracy, and

201   confidence for a purpose can be obtained from a map classified using a scheme dedicated for

202   that particular purpose.

2.3.2. The environmental and ecological scope of a habitat classification scheme

203

204 The scope of an HCS defines which (i) biogeographic region(s), (ii) biological realms (e.g.,

205 pelagic/benthos), and (iii) type of habitats included (e.g., coastal area, estuaries or hard

206 substrata) are covered by the scheme. In some cases, a HCS will have been developed for a

207 specific biological component, study or geographic location, and the resulting habitat types

208 may not be applicable beyond that subject or area. In other cases, schemes have been

209 developed using broad-scale data or using thresholds in ecologically relevant variables

210 (Vasquez *et al.*, 2015).

211 *Variation in the scope of habitat classification shemes*

212 The combined geographical scope of HELCOM HUB and the marine section of EUNIS is the

213 marine waters off the European mainland, including offshore islands, and the archipelagos of

214 the European Union Member States. Some regions are included in the scheme in principle,

215 although knowledge from these areas is more limited, and their habitats descriptions are

216 therefore poorly represented; e.g., the Black Sea and the Canary Islands. The HELCOM HUB

217 and EUNIS schemes cover the entire seabed from the intertidal zone into deeper, subtidal

218 areas (EUNIS also extends into the abyssal zone), as well as some broadscale pelagic

219 habitats. Both schemes are heavily biased towards parts of Europe that have been well-

220 studied and have existing HCSs (Galparsoro *et al.*, 2012). Likewise, both the NISB and

221 CMECS schemes are also designed for a broad set of habitats yet within specific geographic

222 regions, i.e., NISB covers all of Australia's territorial waters between the high tide and out to

223 the limit of the photic zone (depth of 50 – 70 m) and CMECS includes all estuarine, coastal

224 and marine waters under U.S. jurisdiction in North America. Although initially developed for

225 the Gulf of Maine region, the CSH scheme (Valentine *et al.*, 2005) scheme is a generic

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226 classification and can, therefore, be applied to any continental shelf and shelf basin

227 environment globally (excluding some low-latitude environments).

228 Other classifications have an even broader geographical scope. The PHCS was initially

229 developed for use in specific deep-water habitats within North America (Greene *et al*., 1999,

230 2005, 2007). The PHCS has been expanded to include shallow water habitats, Arctic to

231 tropical regions, including Antarctica (Vietti *et al*., 2001) and estuaries (Greene *et al*.,

232 2007b). The upper levels of the HFMHC (Guarinello *et al*., 2010) was designed, from the

233 beginning, to start with the global classification of large marine ecosystems (Sherman and

234 Alexander, 1986). Subsequent levels include distinct ecosystem units, e.g., estuary, and

235 broad, geological formations such as drowned river valley. The classification splits into three

236 and covers the water column, benthos, and human activity/impacts. The flexibility to add

237 user-defined classes at the lower levels of all three strands means the framework can be

238 applied in any geographic location and is not limited by the methods used to observe any of

239 the three classifiable components.

240   *Summarising the influence of habitat classification scope on habitat maps*

241 The sample of HCSs considered within this review span a range of habitats and geographical

242 regions. Some schemes are broad in their scope from design, whereas others have grown to

243 include new areas, such as the PHCS (Greene *et al*. 1999, 2005, 2007) and the CSH,

244 Valentine *et al*., 2005). Classes in locally calibrated classification schemes are more likely to

245 match the observations made in similar habitats or geographical areas. By contrast, classes

246 within broader, generic schemes are likely to have to generalise class descriptions, thereby

247 diminishing the ability of the scheme to reflect localised variation (reduced specificity) in

248 habitats. However, habitat maps generated with broad-scale HCSs are more likely to be

249 compatible with other maps and contribute to national and international mapping efforts.

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250 Furthermore, the output format and classes of maps using broad-scale HCSs will be familiar,

251 and hence more applicable, to more end-users that are already acquainted with the coding and

252 purpose of the selected HCS.

253

2.3.3. The spatial scale covered by a habitat classification scheme

254

255 The seabed can be characterised and classified at different spatial scales ranging from the

256 fine-scale, local environment (~1 – 10s metres), with factors affecting individual organisms,

257 to landscapes and large-scale ecosystems (~100 – 1000s metres) where the substrates, terrain,

258 and oceanographic settings influence biological communities and populations.

259 *Variation in the spatial scale between habitat classification schemes*

260 Progression through both the EUNIS and HELCOM HUB hierarchies results in finer

261 thematic resolution as well as a finer spatial scale, e.g., a level 5 habitat is expected to cover a

262 smaller area than its parent habitat at level 4. Helpfully, both schemes also provide an

263 indication of the minimum spatial footprint for the finest units, e.g., as a working guide,

264 biotope units extends over an area of at least 5 m x 5 m, but can also cover many square

265 kilometres, such as for extensive offshore sediment plains. For minor habitats, such as

266 rockpools and overhangs on the shore, this 'minimum size' can be split into several discrete

267 patches at a site. The NISB scheme may be applied to fairly fine scales, while the upper tiers

268 of the classification hierarchy, which has a reduced number of habitat classes, may be applied

269 to broader, regional scales. The NISB scheme is particularly helpful in that it defines a

270 'reference area' of 9 m^2, for the assessment of habitat and biota dominance. Class modifiers

271 applied to fine-scale features must be applied at the scale of the reference area as a minimum.

272 This reference unit was deemed appropriate for a range of sensing techniques and a practical

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273   measure that can be easily made in the field with the current observation sensors and

274   methods, such as videography and diver.

275   To allow for the varying scales of map production and use, the PHCS (Greene *et al.* 2005,

276   2007), recognises and defines four spatial scales. The macro- and micro-habitats can be

277   nested within the smaller-scale mega- and meso-habitats. The appearance of specific habitat

278   scales can, therefore, be linked to the scale of observation, thereby aiding the production and

279   visual interpretation of the maps e.g. using dynamic segmentation methods such as those

280   detailed by Nasby-Lucas *et al.* (2002). The tiers associated with the HFMHC scheme

281   (Guarinello *et al.*, 2010) are also associated with specific spatial scales, but no strict spatial

282   constraints are set for any level, thereby allowing any project to be fitted within the

283   framework. Equally, CMECS is designed to operate at multiple spatial scales and provides

284   the specificity needed for local-scale applications. Like the previous two schemes, each level

285   within CMECS is associated with a specific spatial scale, ranging from $10 - 1000$ km^2 at the

286   first 'regime' level, to $1 - 100$ m^2 at the final 'biotope' level. As such, CMECS allows the

287   aggregation and assessment of classified units across diverse systems at regional, national or

288   global scales without loss of utility at local levels. These scales are useful in guiding the

289   mapper during the interpretation of both survey observations and the classification scheme.

290   *Summarising the influence of habitat classification schemes scale on habitat maps*

291   The consideration of scale is relevant for several aspects of habitat classification, map

292   production and usage. Firstly, the scale, and associated spatial resolution of a scheme

293   determines which physical or ecological features can be represented on a map and what level

294   of habitat heterogeneity can be captured. It is recognised by most mappers that many spatial

295   units of classified habitat are mixed classes or mosaics. For simplicity, spatial units are

296   typically labelled according to the dominant class and information regarding secondary

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297 habitats either removed or appended as a modifier. HCSs associated with finer spatial scales

298 reduce the need to generalise mosaicked habitats and thereby better reflect heterogeneity at

299 more scales. It should be noted that it is rarely stated within HCSs that units must be mutually

300 exclusive i.e., multiple habitat codes can be attributed with either a proportion or probability

301 and then allocated to a single, spatial unit.

302 Secondly, the scale of the HCS may also determine the type of mapping information, and

303 therefore mapping methodology, required for the classification. For example, deep-water

304 acoustic surveys may not have the required resolution for the identification of habitat classes

305 with small footprints, whereby requiring the use of Autonomous Underwater Vehicles

306 (AUVs)-mounted sonars for data collection. Furthermore, schemes that stipulate minimum

307 mappable units and area thresholds for habitat classes also benefit the mapper and reduce the

308 number of subjective decisions that might be needed during the production of maps. The final

309 issue is that the scale addressed by the HCS also defines the type of management supported

310 by the maps. For example, localized impact assessments will require maps with a sufficient

311 resolution for the accurate prediction of impact.

312   **2.3.4. The thematic resolution covered by a habitat classification scheme**

313 The thematic resolution specifies how fine the increments are between classes within a parent

314 habitat. For schemes with a high thematic resolution, one might expect a high number of

315 classes, each separated by relatively small differences in environmental or biological

316 variables. By contrast, low thematic resolution would entail a small number of coarser habitat

317 classes.

318   *Variation in the thematic resolution between habitat classification schemes*

319 The most detailed levels in the EUNIS and HELCOM HUB classification schemes are

320 predominantly defined by biotopes and therefore separates classes according to small, but

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321   significant, biological differences in otherwise similar habitats. In EUNIS, many of the

322   biotopes at levels 5 and 6 originated from statistical clustering analysis and expert

323   interpretation of data from diver surveys and intertidal surveys (rather than grab or remote

324   video) in the EC Life Nature-funded BioMar project (Connor *et al.* 1997). Equally, level 5

325   biotopes in the HELCOM HUB scheme were defined by analysing more than 50,000 data

326   observations (i.e., video data, diving observations, grab samples) using spatial and statistical

327   methods as well as expert judgment.

328   The PHCS (Greene *et al.* 2005, 2007), CSH (Valentine *et al.*, 2005) and the NISB scheme

329   use modifiers to provide greater thematic resolution and flexibility for the finest classes

330   present. The PHCS uses single letter modifiers that describe specific aspects of geology,

331   biology, topography and seabed texture. These modifiers can be allocated to any of the six-

332   letter habitat codes used by the scheme. There is no limit to the number of modifiers that can

333   be attributed to each habitat code. Similarly, three themes within the CSH classification also

334   provides modifiers that allow the user to describe 'biological' 'habitat association and usage'

335   as well as short descriptors for 'community disturbance and recovery'.

336   Developing the use of modifiers further, the Hierarchical Framework of Marine Habitat

337   Classification for Ecosystem-Based Management (Guarinello *et al.*, 2010) scheme permits

338   the use of user-generated classes (typically at the 'data analysis' level) and modifiers at most

339   of the levels within the classification, which therefore allows for any type and level of

340   thematic resolution. Units of information at the lowest levels of the framework can include a

341   variety of relevant information such as absolute values of abundance, dietary composition for

342   dominant species, rates for species-specific ecosystem functions and observed ranges for

343   important physico-chemical characteristics.

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344   *Summarising the influence of thematic resolution on habitat maps*

345   For the majority of the schemes, the finest classes are resolved according to biological

346   characteristics of sessile benthic species. In some HCSs, more resolution is provided through

347   the use of class modifiers rather than distinct classes. Such information displayed with

348   classified habitats on the same map is likely to be valuable to a variety of map users.

349   However, modifiers that unduly extend the basic classification of a habitat (i.e. 'what it is')

350   are likely to complicate the habitat representation into maps, their interpretation by end users

351   and reduce comparability between maps.

352   The greatest level of thematic resolution differs substantially between HCSs. This is due to

353   either a shortage of information for the formation and validation of these most detailed

354   classes or that the overall purpose and scope of the HCS does not concern itself with detailed

355   biological information. Regardless of the HCS used, mappers must be aware of the level of

356   the classification that can be safely supported by the survey data, e.g., what level of

357   community classification can be supported by epibenthic video, and what the intended

358   purpose of their map will be. Equally, to improve the compatibility of maps, attempts should

359   be made not just to standardise the use of HCS (or suite of HCSs) for mapping but also to set

360   the level of classification within a scheme for a specific mapping technique (matched to a

361   specific purpose).

362

363   **2.3.5. The structure of a habitat classification scheme**

364   The structure of HCS can be either hierarchical or flat, as well as nested or un-nested (parallel

365   hierarchies). For hierarchical structures, the highest tiers typically separate observations into

366   coarse classes using broad physical and chemical variables. Lower tiers proceed to refine the

367   classification based on more localised, physico-chemical variables, as well as biological

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368   information on the composition of the communities present. Flat classification structures do

369   not nest classes under predefined physico-chemical pathways. As such, flat structures allow

370   the user to combine physico-chemical classes with independent biological classes – such

371   classifications may not be possible within hierarchical structures if the required biological

372   class is not nested within the observed physico-chemical pathway. The restrictive nesting of

373   classes within hierarchical structures is only a significant issue when the training data used to

374   develop the HCS was not reflective of habitat conditions apparent throughout the intended

375   area of application.

376   *Variation in structure between habitat classification schemes*

377   EUNIS, HELCOM HUB, and CMECS (substrate and biotic components only) are all

378   hierarchical schemes with six levels of marine classification. For example, the first two levels

379   of the CMECS scheme separate observations according to (i) salinity, geomorphology, and

380   depth, and then (ii) by substrate type or water mass characteristics - additional levels sort

381   observations by (iii) physical zones, (iv) macrohabitats (large and physically complex units

382   containing several habitats), (v) habitats defined by physical and energy characteristics and

383   finally, (vi) by characteristic biological composition. This structure is similar to both EUNIS

384   and HELCOM HUB. For both systems, the structure of the hierarchy assumes that classes at

385   the same level are mutually, and hence spatially, exclusive. Equally, specific communities

386   and biotopes in the lower levels of the hierarchy are nested under specific physical conditions

387   (defined by higher levels) and are not transferable between physical habitats. The NISB

388   scheme is also hierarchical but with fewer levels. At the higher levels of the hierarchy, the

389   NISB scheme assumes spatially exclusive habitats. The scheme uses 'decision rules' for

390   attributing habitat classes and for allocating geomorphic, biological and environmental

391   modifiers. These decision rules allow simple, unambiguous interpretation of survey data and

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392   facilitating the objective and consistent assignment of habitat classes. The decision rules are

393   framed to be as sensor/method-independent as possible.

394   The PHCS is also hierarchical but has an un-nested structure. This scheme has separate

395   attribution pathways for the classification of small-scale (megahabitats and mesohabitats) and

396   large-scale (macrohabitats and microhabitats). The small-scale classification uses various

397   environmental parameters to provide increasingly finer thematic classes. The large-scale

398   pathway initially attributes the seafloor according to geological and coarse biological classes,

399   and then followed again by textural attributes. Similarly, the lower levels of the HFMHC

400   (Guarinello *et al*., 2010) scheme has three parallel (un-nested) 'benthic', 'water column' and

401   'human' hierarchies. The use of separate components within the framework avoids the

402   difficulty of generating a single hierarchy for fundamentally different domains and the

403   flexibility and structure of this framework allow for a broader storage of information.

404   However, the interaction of the three hierarchies generates a large number of unique habitat

405   classes.

406   The CSH (Valentine *et al*., 2005) scheme is quite different in structure to the other schemes

407   considered, as it is structured round eight, non-hierarchical seabed 'themes' as the major

408   subject elements of the classification. These themes are seabed topography, dynamics,

409   texture, grain size, roughness, fauna and flora, habitat association and usage, and habitat

410   recovery from disturbance. The themes all reside at the top level (i.e., are not hierarchical)

411   and are applied to the classification of each site. Below the themes, a sequence of more

412   hierarchical subclasses, categories, and attributes address habitat characteristics with

413   increasing detail. This scheme was developed to be used exclusively for mapping purposes.

414   As such, it was designed with a flexible structure to account for both data availability while

415   maintaining a framework that is considered the best method of representing the habitats on

416   maps based on the classification. The classification can accommodate new classes,

417   subclasses, categories, and attributes, and it can easily be modified or expanded to address

418   habitats of other regions.

419   *Summarising the influence of habitat classification scheme structure on habitat maps*

420   Most of the HCSs adopt a hierarchical structure, with the initial levels typically referring to

421   broad-scale physical variables, biogeographic or domain regions. Classes within lower levels

422   are either nested under higher level classes or are open and unrestrained by the high-level

423   class. Hierarchical schemes allow habitats to be aggregated to a coarser level, thus allowing

424   comparisons to be made between different studies using the same scheme, even when

425   different levels of detailed information are available. These comparisons, however, are only

426   possible if the HSC is interpreted consistently, and rests upon a thorough understanding of

427   the scheme and how best to classify information using the scheme.

428   A nested structure will provide a smaller but more targeted number of possible classifications

429   – this is likely to benefit consistency and compatibility between studies. However, Galparsoro

430   *et al.* (2012) reported that for EUNIS, a nested hierarchy, some communities occur in

431   different main branches of the hierarchy due to their variations in associated depth or

432   sediment type, whereas in reality, they are very similar. Equally, some communities only

433   occur in a single branch of the hierarchy because they are mainly associated with certain

434   physical conditions; however, if the same community is observed with a different set of

435   physical conditions, then it would not fit precisely in the existing category. Schemes with an

436   open structure provide the user of the classification more flexibility to generate classes not

437   previously documented during the development of the classification. Open, un-nested

438   structures are perhaps best-suited for mapping in areas that may be poorly represented within

439   more trained and structured classifications.

2.3.6. Compatibility of a habitat classification scheme for habitat mapping

441 Although several HCS have been designed specifically for mapping studies, this was not the

442 intended purpose for all of the HCSs used in habitat mapping. As such, some of the decision

443 points or environmental and ecological parameters that structure HCSs may not be routinely

444 collected, or possible to observe, using the methods routinely deployed for marine habitat

445 mapping. As such, the ease with which an HCS can be applied to mapping data can vary.

446 HCSs that are designed specifically for mapping are more likely to be aligned to the

447 commonly collected variables and include quantitative thresholds or decision points

448 appropriate for these types of data and value ranges.

449 *Variation in the compatibility of mapping techniques between habitat classification*

450 *schemes*

451 EUNIS has been used extensively for mapping and modelling (e.g., EUSeaMap, Vasquez *et*

452 *al.*, 2015; Populus et al., 2017) efforts and have collectively produced a pan-European habitat

453 map for a coordinated approach to marine conservation, assessment of the status of marine

454 waters and spatial planning. Until now, HELCOM HUB has been applied in national case

455 studies only (e.g., Schiele *et al.* 2014, 2015). However, the use of the light penetration depth

456 as a major structural variable in the HELCOM HUB scheme means that additional

457 observations (not typically collected during marine habitat mapping) or external modelling

458 outputs must be combined with the mapped variables to generate a classification. The same

459 holds true for EUNIS regarding light availability and wave exposure at the seabed. The NISB

460 scheme is interesting in that it provides an umbrella scheme that can adopt and amalgamate

461 other classification schemes into its hierarchical system, i.e., the NISB scheme can be used to

462 translate existing local habitat maps into a single, aligned product (Hilbert *et al.*, 2007). The

463   flexibility of this scheme allows old maps and mapping data to be translated into new and

464   aligned products.

465   The EUNIS scheme has been criticised for incompatibilities between the information used to

466   define classes and that typically collected during a mapping survey. Levels 5 and 6 of the

467   hierarchy are based on data from a wide variety of sampling techniques; as a result, they

468   describe different aspects of seabed habitats. For example, some biotopes describe infaunal

469   communities, while others describe epifaunal communities. Robinson *et al.* (2009) argued

470   that some biotopes can only be identified if the method used during survey work is the same

471   as the method used to originally define that biotope. For example, the characteristic species

472   defining the level 5 biotope "*Hesionura elongata* and *Microphthalmus similis* with other

473   interstitial polychaetes in infralittoral mobile coarse sand" are tiny polychaetes that would be

474   grossly under-sampled using all but the finer meshes for sieving sediment. The 1 mm sieve

475   used as standard on offshore surveys would not retain meiofauna such as these polychaetes

476   (Parry, 2014).

477   The classes within the PHCS of Greene *et al.* (1999, 2005, 2007) are mostly defined by their

478   geological character. As such, the scheme is well suited for the detection of habitats using

479   acoustic remote sensing and thereby increases the confidence in the resulting classification.

480   However, the biological classes are coarse, exclusively epifaunal and taxonomically distinct,

481   which is perhaps unreflective of the typical composition of many seafloor communities and

482   means that seafloor biota only have a fairly minor influence on the overall classification. The

483   CMECS scheme is designed to be compatible with a range of sampling methods, e.g.,

484   cameras and certain acoustic devices can be used to identify the higher classification levels,

485   while traditional point sampling methods, such as sediment sampling using grabs, can be

486   used for the lower levels of classification. Equally, the sediment classes within CMECS are

21

487 aligned to the Folk (1954) sediment classification, which is an established scheme in marine

488 habitat mapping. This differs from the EUNIS classification which is underpinned by a

489 'modified' (simplified) Folk classification.

490 *Summarising the influence of habitat classification scheme compatibility on habitat maps*

491 The ease with which habitat mappers can integrate HCSs is based on the compatibility of the

492 scheme's classifying variables with survey outputs. For example, in the PHCS presented by

493 Greene *et al*. (2005, 2007) several of the classification attributes are generated specifically

494 from common acoustic parameters such as depth (for bathymetric zones, slope, and rugosity)

495 and backscatter (for hardness). Most of the geomorphological classes for other attributes are

496 easily identifiable from full coverage bathymetric surfaces. However, it is clear that the ease

497 and accuracy of classification also varies between habitat types. For example, it may be

498 relatively straightforward to distinguish rock from muddy habitat in multibeam echosounder

499 backscatter data, while there may be no clear boundary between coarse and mixed sediment.

500 At the more detailed levels, many of the differences in the communities cannot be

501 distinguished in acoustic data and therefore they are difficult to map.

502 Difficulties in finding an appropriate class can be further compounded when HCSs are biased

503 towards the habitats used in the initial development of the classification. For example, the

504 marine component of EUNIS is primarily based on the British-Irish BioMar scheme, which

505 was originally developed largely using UK near-shore data, primarily from grab sampling

506 and, to a lesser extent, diver surveys (Connor *et al*., 2004). This means that EUNIS is less

507 well-developed for offshore habitats, particularly those occurring on hard substrates.

508 Furthermore, EUNIS is arguably less well developed for interpretation of data from remote

509 video techniques which sample different parts of a biological community than divers or grab

510 samples, and at a different scale, therefore posing difficulties in matching the communities

22

511   from video/photographic techniques to the statistically driven clusters from grab sample and

512   diver surveys. Similarly, certain classifications have been developed to use certain data types,

513   e.g., schemes developed for the interpretation of satellite imagery (e.g., Mumby and Harborne

514   1999), and may therefore not apply to data obtained from other sources.

515

3. Recommendations for the use of marine habitat classification schemes in marine

517   **mapping**

518   This review will firstly summarise the most influential aspects of HCSs in marine habitat

519   mapping and consider how this influence can be accounted for, or reduced, in habitat

520   mapping. Some of the common limitations associated with the use of HCS in habitat mapping

521   are often propagated by how habitat mappers use HCSs rather than being issues implicit

522   within the schemes themselves – these issues are also discussed below and recommendations

523   are provided.

524   *Defining 'actual' and 'potential' habitats within mapping*

525   Many habitat maps present an unspecified mixture of 'realised' and 'potential' habitats when

526   using HCSs. For example, the upper classification levels of many HCSs divide areas by

527   geomorphology and rely on acoustic survey data to achieve this delineation. Continuous

528   bathymetric surfaces can, therefore, confirm the presence of large, physical features from

529   observations. Observations of biotopes are only provided by point (e.g., grab or photographic

530   still) or line (e.g., video transect) sampling during ground truthing. The continuous

531   distribution of the biotopes is then predicted using geo-spatial modelling or expert judgment,

532   meaning that the resulting distribution is an extrapolated product not fully supported by direct

533   observation (unless one is mapping a biogenic biotope with a detectable structure). The

534   predictor variables typically used to model the distribution of these biotopes also fail to

23

535   represent influential biological processes such as competition, predation, and dispersal

536   (Brown *et al*., 2011). As such, one is modelling 'potential' habitat for that biotope, which

537   may or may not be occupied by the species constituting that biotope. The distinction between

538   features that are realised versus potential habitat is rarely explicitly expressed when

539   presenting mapped habitat classes. A lack of specificity may contribute to inaccurate

540   assessments of the confidence of habitat maps by end-users, uncertain assessments of extent,

541   and ambiguity about the relevant management action for sites and feature. It is therefore

542   recommended that maps label habitats and biotopes with potential (modelled and potentially

543   not occupied) and realised (delineated by direct observation) habitat labels or modifiers.

544   *Improvements to the consistency of habitat classifications*

545   The use of habitat classification involves accepting some of the inherent assumptions

546   associated with HCSs. An assumption common to all schemes is that all habitats can be

547   classified into distinct and identifiable classes. It is often the case that observations, collected

548   during habitat mapping surveys, fail to fall neatly into classes within a scheme. The presence

549   of ecotones and mosaics of heterogeneous habitat reduces the clarity of class membership,

550   and hence the ability to accurately reflect conditions on the seabed.

551   The difficulty in classifying a continuous variable into a discrete class is further complicated

552   when HCSs lack a quantitative definition, or clear 'decision rules' for each class. Also, as

553   habitat mapping became heavily based upon physical measurements in the past 15 years (e.g.,

554   Al-Hamdani and Reker, 2007; Cameron and Askew, 2012, Vasquez *et al*., 2015, Galparsoro

555   et al., 2015), there came an increasing demand for quantitative definitions. Without this

556   information, qualitative classifications are often open to subjective interpretation and

557   inconsistencies between studies or adjoining maps.

24

558 Common schemes, such as EUNIS and CMECS (Federal Geographic Data Committee,

559 2012), lack quantitative definitions that could define classes. For EUNIS, the absence of these

560 definitions is a result of it being constructed from several classification schemes, making it

561 difficult to achieve consensus on what those definitions should be. The large part of the

562 scheme that originated in Connor *et al.* (2004) was designed primarily as a biological

563 classification system, with the physical descriptions at the higher levels being convenient

564 groupings that did not necessarily need to adhere strictly to any definitions.

565 HELCOM HUB provides quantitative delineation and classification rules within each of the

566 classification levels. As an example, the system differentiates between soft and hard bottom

567 substrata (Level 3), by a spatial coverage percentage of hard substrates within a given area

568 (HELCOM, 2013). The latter also holds true for the delineation between infaunal and

569 epifaunal dominated biotopes (Level 4), and between epifaunal communities (Level 5) and

570 dominating species (Level 6).

571 Other HCSs also incorporate quantitative thresholds, for example, the Australian NISB

572 habitat classification also uses decision rules (such as quantitative measures, percentage cover

573 thresholds, and particle size bands) at all levels of the hierarchy and for the class modifiers.

574 The PHC scheme uses objective methods to calculate specific attributes, such as rugosity and

575 slope, to reduce subjective attribution and delineation, and clear thresholds that separate

576 classes e.g., depth ranges for megahabitats or particle size for substrata. However, some

577 attribute classes lack quantitative definitions which could lead to subjectivity, and hence

578 variation, during the manual delineation of features. The use of quantitative attribution will

579 also provide a more robust basis for: (i) initial classification of habitats; (ii) the estimation of

580 how well the observation fits the assigned class; and (iii) greater certainty about the detection

581 of change over time during repeat mapping. Quantitative thresholds and class definitions

582 should not be specific to certain sampling devices or biased towards the survey techniques

583 that were used to initially define classes. Ideally, the class or biotope description should

584 include an indication of how the biotope may appear using a variety of survey techniques.

585

586 *The influence of the structure of a classification scheme on a habitat map*

587 HCSs designed for habitat mapping, and aligned to the types of information typically

588 collected, are likely to be easier to use, reduce subjectivity during the classification of seabed

589 information and generate more accurate maps. A single, nested hierarchical structure

590 probably generates the most consistent classification between studies, but typically provide

591 less breadth and flexibility during the classification process. It is recommended that rigid,

592 hierarchical systems need to have a good system for updating either their structure or

593 classified units as new delineations are required.

594 Modifiers are an extremely useful structural component for appending additional information

595 onto a class without necessarily complicating the production or display of habitat maps. For

596 example, modifiers could be used to represent: (i) observations on the condition of habitats;

597 (ii) evidence of anthropogenic pressures (e.g. litter, physical alteration); (iii) labels for

598 habitats that are hard to classify (e.g. fall between classes or units containing a mosaic of

599 classes); or (iv) associations with other biological features not covered by the HCS such as

600 large shoals of fish. To ensure their consistent application of modifiers, HSCs should once

601 again provide detail on when and how to apply modifiers.

602 *Contextual attribution of habitat codes within habitat classification schemes*

603 A scheme name or code for a habitat provides a unique and brief title for the classified

604 feature. Habitat classes are typically supported by a fuller description that many contain, for

605 example, the identity and relative abundance of characterising species as well as the

26

606 prevailing physico-chemical conditions present. However, this supporting information is

607 typically detached from the map and just the class names are presented. It is recommended

608 that all HCSs be available on an online vocabulary server and that digital maps include a

609 unique resource identifier for each habitat class. Although essential, the name of a particular

610 habitat may not necessarily be the most informative or valuable attribution for a map feature.

611 It is likely that additional attribution providing details, for example, on class sensitivity,

612 rarity, or ecosystem services provided (e.g., Salomidi *et al.*, 2012; Galparsoro *et al.*, 2014)

613 may be of greater interest to the end user. It is also recommended that HCSs provide a

614 broader array of attribution with each class. This will make it easier for maps to display

615 alternative types of information as well as more contextual information for the class name.

616

Providing multi-purpose marine habitat maps

618 Habitat mapping is conducted for a multitude of purposes and this is reflected in the number

619 and variety of HCSs available. Classification schemes can be either specialised or generic.

620 Generic classifications are best suited for baseline data, inventory mapping and marine spatial

621 planning. Specialised classifications provide greater specificity, and therefore applicability,

622 for specific topics or management issues (e.g., climate change, fisheries, conservation).

623 Management outcomes are presumed to be more effective when based on specialised HCS

624 aligned to the topic of interest. Despite this, most mapping studies tend to produce just one

625 map, or set of maps, based on just one adopted HCS scheme. Based on the cost and effort

626 required to gather the data used for habitat mapping, the practice of producing just one map,

627 based on one HCS per study, is potentially inefficient and narrows greatly the breath of the

628 mapping exercise. Each use or purpose should be linked to the most informative and

629 appropriate classification scheme. It is therefore recommended that habitat mappers use

27

630   several HCSs to generate multiple map products, each with a dedicated purpose. For

631   example, a suite of maps that offers the greatest utility might include, among others,: (i) a

632   generic, descriptive map for inventory purposes, (ii) a map attributed according to

633   representativity, rarity or conservation value for the protection of species and habitats (design

634   of Marine Protected Areas networks), (iii) sensitivity maps for supporting marine spatial

635   planning and management, (iv) a map of ecosystem services for regional valuations and

636   assessments, (v) maps of essential fish habitat for fisheries management, and (vi)

637   geomorphological and surficial sediment maps for sediment dynamics, extraction and mining.

638   The production of a suite of map products does not hamper our ability to standardise or

639   merge maps within a thematic area, nor does it necessarily represent a significant additional

640   workload for mappers. The ability of mappers to produce multiple maps, based on several

641   classification schemes, can be simplified if translation tables (tables that map classes of one

642   HCS to units of another HCS) are made available. It is therefore recommended that mappers

643   use multiple HCSs to produce a suite of maps and that this activity is supported by the

644   development of translation tables (e.g. JNCC, 2018).

645

646   4. Conclusions

647   Marine HCSs differ greatly within six key properties, due in part to their initially intended

648   application and structure (i.e. whether they follow a strictly hierarchical approach to

649   classification and how readily they incorporate modifiers for the incorporation of greater

650   detail). Consequently, each HCS has specific strengths and weaknesses. These strengths and

651   weaknesses, along with the inherent assumptions associated with the classification process,

652   modify the final representation of habitats when mapped. It is important for mappers to be

653   aware of how these properties and assumptions are transferred into marine habitat maps, and

28

654 whether these constrain their subsequent use for a wider variety of applications. Equally,

655 decisions on how mappers use HCSs within the mapping process, which is independent of the

656 properties associated with the HCS, also introduces additional artefacts and biases. Having

657 identified all of these issues, recommendations have been provided for improving HCSs for

658 marine mapping as well as enhanced working practices for mappers using these schemes. For

659 example, limiting interpretation of data to fit only one HSC compromises the information we

660 can communicate through our maps and limits their use to a wider range of stakeholders. It is

661 hoped that implementation of these recommendations will lead to: (i) greater certainty and

662 usage within mapping studies; (ii) more consistency between studies and adjoining maps; and

663 (iii) increased use of mapped products by a greater diversity of end users.

664

665 **5. Acknowledgements:**

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Table 1. Marine (benthic) habitat classification schemes used to document the variation in the six scheme properties considered.

Habitat Classification Scheme	Description	Examples of usage
European Nature Information System (EUNIS) - Davies *et al*. (2004) http://eunis.eea.europa.eu/	EUNIS is a pan-European habitat classification scheme developed between 1996 and 2001 by the European Environment Agency (EEA) (Davies *et al*., 2004). It considers both marine and terrestrial habitats in Europe. The geographical scope of the EUNIS marine scheme is the marine waters off the European mainland, including offshore islands (British Isles, Cyprus, Iceland, but not Greenland), and the archipelagos of the European Union Member States (Canary Islands, Madeira, and the Azores). EUNIS marine scheme covers the entire seabed from the intertidal zone to the abyss, and also includes a section of pelagic habitats. In the marine sector, it is based on the Joint Nature Conservation Committee (JNCC) Marine Habitat Classification for Britain and Ireland (Connor *et al*., 2004) and habitat types developed by the Barcelona and Helcom marine conventions (Barcelona Convention, 1998; Helsinki Commission, 1998).	EUNIS supports inventory mapping (EMODnet), ecosystem-based management (Andersen et al., 2018) and policy implementation Marine Strategy Framework Directive (Council Directive 2008/56/EC).
HELCOM Underwater Biotope and Habitat classification system (HELCOM HUB) – HELCOM (2013) http://www.helcom.fi/baltic-sea-trends/biodiversity/helcom-hub	HELCOM HUB was developed to be a comprehensive classification system for marine biotopes of the Baltic Sea (HELCOM, 2013). Its origins go back to the HELCOM EC-NATURE Red List Project (HELCOM, 1998) which was a first Baltic Sea wide classification scheme based on substrate type and bathymetry. Its classification rules mainly relied on expert judgment and biological classification criteria were not included. In 2007, the goal was set to renew the Red List Classification system by a HELCOM Red List Biotope Expert Group. Previous attempts had been made to apply EUNIS to the Baltic Sea region but the system was recognized to poorly represent its biotic and abiotic characteristics (Galparsoro *et al*., 2012). Nevertheless, HELCOM HUB was to be compatible with EUNIS and account for available biological information on	Supports the national implementation of the Marine Strategy Framework Directive (Council Directive 2008/56/EC).

	marine biotopes from the Baltic Sea. HELCOM HUB is primarily focused on benthic habitats/biotopes - the pelagic environment is only dealt with in the upper part of the classification system. As one major improvement, HELCOM HUB provides clear quantitative classification rules for both abiotic and biological criteria. It was therefore used as a basis for the development of the national classification system of the German Red List of Threatened Habitat Types for both the North and the Baltic Sea (Finck et al. 2017).	
Potential Habitat Characterization Scheme (PHCS) - Greene *et al.* (1999, 2005, 2007)	This classification covers deep-water habitats within North America and has been expanded to include shallow water habitats, arctic to tropical regions, including Antarctica (Vietti *et al.*, 2001) and estuaries (Greene *et al.*, 2007b). This scheme has been specifically developed for seafloor mapping and uses common mapping information such as multibeam echosounder data, video, photographs taken with still cameras and seafloor samples from grabs. The attributions used to classify the seafloor are mainly based on physical parameters and features and therefore, has a 'bottom-up' structure. The classification scheme is unusual in that it recognises four spatial scales. The first three scales can be defined with acoustic methods whereas the finest scale habitats can only be delineated with direct observation (via video, photographic still imagery, diver observations or seafloor sampling) Greene *et al.* (2005, 2007).	Fisheries management (Greene *et al.*, 2005, 2007)
Hierarchical Framework of Marine Habitat Classification for Ecosystem-Based Management (HFMHC) - Guarinello *et al.* (2010)	This classification framework is specifically designed for promoting ecosystem-based management. The upper levels of the scheme start with the global classification of large marine ecosystems. Subsequent levels include recognizable ecosystem units; e.g. estuary, and broad, geological formations such as drowned river valley. The flexibility to add user-defined classes at the lower levels of all three strands means the framework can be applied in any geographic location and is not limited by the methods used to observe any of the three strands. The framework incorporates the central concepts of ecosystem-	Ecosystem-based management (Guarinello *et al.*, 2010)

	based management within the structure of the framework. This ensures that the products of this HCS reflect the values and objectives of ecosystem-based management.	
Classification of Sublittoral Habitats (CSH) - Valentine *et al.* (2005)	This classification scheme was designed to describe and classify habitats in terms of geological, biological and oceanographic attributes. It is unusual in that the scheme also captures information on the effects of natural and anthropogenic processes on habitats. The purpose of the classification is to provide a foundation for scientific research and environmental management of seafloor habitats across a relatively large, regional area. Although initially developed for the Gulf of Maine region (an area that reaches depths of approximately 400 m but also has submarine canyon heads that incise the continental shelf and reach depths of up to 800 m), the scheme is a generic classification and can therefore by applied to any continental shelf and shelf basin environment globally (excluding some low-latitude environments).	Fisheries management (Valentine *et al.*, 2005)
Australian National Intertidal/Subtidal Benthic Habitat Classification Scheme (NISB) http://lwa.gov.au/products/pn21267	The NISB scheme was developed to identify a "uniform definition of communities, habitats and ecosystems" at both state and national scales, and spatial information that is informative for assessing critical climate change issues and the detecting change or loss of habitats or communities. The proposed scheme covers all of Australia's territorial waters between the high tide and the approximate outer limit of the photic zone (depth of 50 – 70 m).	Inventory mapping of ecoregions (bioregional subregions)
Coastal and Marine Ecological Classification Standard (CMECS) - Madden *et al.* (2005) https://www.cmecscatalog.org/cmecs/	CMECS was developed by the National Oceanic and Atmospheric Administration (NOAA) and NatureServe. The scheme is founded on existing schemes (e.g. Cowardin *et al.* (1979), Dethier (1992), Greene *et al.* (1999), Allee *et al.* (2000), Zacharias and Roff (2000) and Connor (2004)). CMECS includes all estuarine, coastal and marine waters under U.S. jurisdiction in North America. This includes wetlands, the intertidal zone, coastal and deep-water habitats (including the Great Lakes) as well as the pelagic realm.	Inventory mapping (Madden *et al.*, 2005)