Holistic Environmental Approaches and Aichi Biodiversity Targets: accomplishments and perspectives for marine ecosystems

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In order to help safeguard biodiversity from global changes, the Conference of the Parties developed a Strategic Plan for Biodiversity for the period 2011-2020 that included a list of twenty specific objectives known as the Aichi Biodiversity Targets. With the end of that timeframe in sight, and despite major advancements in biodiversity conservation, evidence suggests that the majority of the Targets are unlikely to be met. This paper is part of a series of perspective pieces from the 4th World Conference on Marine Biodiversity (May 2018, Montréal, Canada) to identify next steps towards successful biodiversity conservation in marine environments. We specifically reviewed holistic environmental assessment studies (HEA) and their contribution to reaching the Targets. Our analysis was based on multiple environmental approaches which can be considered as holistic, and we discuss how HEA can contribute to the Aichi Biodiversity Targets in the near future. We found that only a few HEA articles considered a specific Biodiversity Target in their research, and that Target 11, which focuses on marine protected areas, was the most commonly cited. We propose five research priorities to enhance HEA for marine biodiversity conservation beyond 2020: (i) expand the use of holistic approaches in environmental assessments, (ii) standardize HEA vocabulary, (iii) enhance data collection, sharing and management, (iv) consider ecosystem spatio-temporal variability and (v) integrate ecosystem services in HEA. The consideration of these priorities will promote the

value of HEA and will benefit the Strategic Plan for Biodiversity.

1 **Holistic Environmental Approaches and Aichi Biodiversity**
2 **Targets: accomplishments and perspectives for marine**
3 **ecosystems**

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Abstract

In order to help safeguard biodiversity from global changes, the Convention on Biological Diversity developed a Strategic Plan for Biodiversity for the period 2011-2020 that included a list of twenty specific objectives known as the Aichi Biodiversity Targets. With the end of that timeframe in sight, and despite major advancements in biodiversity conservation, evidence suggests that the majority of the Targets are unlikely to be met. This paper is part of a series of perspective pieces from the 4th World Conference on Marine Biodiversity (May 2018, Montréal, Canada) to identify next steps towards successful biodiversity conservation in marine environments. The aim of our work was to discuss the relevance of Holistic Environmental Assessment (HEA) in regards to the Aichi Biodiversity Targets. We reviewed multiple environmental approaches which could be considered as holistic, and we discuss how HEAs can contribute to the Aichi Biodiversity Targets in the near future. We found that only a few HEA articles considered a specific Target in their research, and that Target 11, which focuses on marine protected areas, was the most commonly cited. We propose five research priorities to enhance HEAs for marine biodiversity conservation beyond 2020: (i) expand the use of holistic approaches in environmental assessments, (ii) standardize HEA vocabulary, (iii) enhance data collection, sharing, and management, (iv) consider ecosystem spatio-temporal variability, and (v) integrate ecosystem services in HEAs. The consideration of these priorities will promote the value of HEAs and will benefit the Strategic Plan for Biodiversity.

1. Introduction

44

45   In 2010, the 10th Conference of the Parties revised and updated the Strategic Plan for

46   Biodiversity from the Convention on Biological Diversity (CBD), which included the Aichi

47   Biodiversity Targets for 2011-2020 (Secretariat of the CBD, 2010). The mission of the Strategic

48   Plan for Biodiversity is to "take effective and urgent action to halt the loss of biodiversity in

49   order to ensure that by 2020 ecosystems are resilient and continue to provide essential services

50   […]" (Secretariat of the CBD, 2010). According to United Nations (1992), biodiversity refers to

51   "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine

52   and other aquatic ecosystems and the ecological complexes of which they are part; this includes

53   diversity within species, between species and of ecosystems". Yet, despite recent small- and

54   large-scale conservation and management efforts, including the development of global protected

55   area networks (Butchart et al., 2015), evidence suggests that most of the Targets are unlikely to

56   be met (Secretariat of the CBD, 2014) as species declines and extinctions continue to occur

57   (Tittensor et al., 2014).

58   With the end of the Strategic Plan for Biodiversity in sight, the time is ripe to reflect on

59   accomplishments thus far and to identify the next steps towards successful biodiversity

60   conservation in marine ecosystems. These steps will be critical to meet the Sustainable

61   Development Goal 14, which aims for the conservation and sustainable use of the oceans, seas,

62   and marine resources by 2030 (SDG, 2019). These topics were tackled during the 4th World

63   Conference on Marine Biodiversity held in Montréal, Canada, in May 2018, which gathered

64   marine biodiversity experts from around the world. A mentoring program was devised to bring

65   senior and early-career scientists together to address this challenge, which resulted in a series of

66   perspective pieces, including this article. Holistic Environmental Approaches (HEA) were

67   identified as crucial to marine biodiversity conservation by program participants.

68   In the present study, we define HEAs as environmental planning, assessment, management, or

69   monitoring strategies that use a whole-system approach to explicitly consider and prioritize

70   ecosystem complexity. Holism is dependent on components, connections, and boundaries of the

71   considered ecosystems. While HEAs focus on natural ecosystems, they may include additional

72   dimensions (*e.g.* social, cultural and economic) relevant to the ecosystem under consideration.

73   There is little doubt that the complexity of ecosystems must be considered for successful marine

74 biodiversity conservation, yet the contribution of HEAs to marine biodiversity conservation in

75 general and to the Aichi Biodiversity Targets in particular is unclear. In this perspective paper,

76 we review the prevalence of HEAs in the peer-reviewed marine biodiversity literature and

77 discuss their relevance to reaching the Aichi Biodiversity Targets, with a focus on the ecological

78 dimension of HEAs. We then propose research priorities to enhance HEAs for marine

79 biodiversity conservation beyond 2020.

80

81

82 ## 2. Literature review

83 ### 2.1. Methodology

84 To better understand the uses of HEAs and their relevance for the Strategic Plan for Biodiversity,

85 we searched the peer-reviewed scientific literature between January 1990 and July 2019

86 (inclusive). We used the *ISI Web of Knowledge* database and we queried the title, keywords, and

87 abstract of original research articles. Non-peer reviewed literature, such as technical reports or

88 assessment tools, were not included in this review as we considered that it could produce an

89 important bias by the selection of studies related only to a specific region or for a specific use.

90 We constrained our search to environmental studies by using the search terms *ecology*,

91 *ecosystem*, *environment*, *habitat*, *species* and *biodiversity* as an initial filtering criteria (Table 1).

92 We then further selected articles that focused on *marine* environments only.

93 A list of HEAs was established by gathering expert opinion from researchers in the field of

94 marine ecology and environmental conservation. This process led to the inclusion of nine HEAs:

95 *adaptive management* (Stankey, Clark & Bormann, 2005), *cumulative impact assessment* (Jones,

96 2016), *ecosystem-based management* (Link, 2002; Pikitch et al., 2004; Levin et al., 2009),

97 *integrated management* (Cicin-Sain & Belfiore, 2005), *marine spatial planning* (Santos et al.,

98 2019), *social-ecological networks* (Baggio & Hills, 2018), *strategic environmental assessment*

99 (Gunn & Noble, 2009; 2011), *sustainable resource management* (Bringezu & Bleischwitz,

100 2017), and *systematic conservation planning* (Margules & Pressey, 2000). We used all HEA

101 collectively as a search query on the initial corpus, then each HEA was queried individually to

102 determine their prevalence in the literature (Table 1). Finally, we used the search term *Aichi* in

103 order to determine if and how Aichi Biodiversity Targets were considered in HEA studies.

104

105   2.2.   Prevalence of HEAs in the marine biodiversity literature

106   Our review identified 1,648 research articles related to biodiversity studies that used any of the

107   identified HEAs, with 505 articles targeting marine environments. We found that the term

108   *ecosystem-based management* was the most represented HEA (40.2 %), followed by *marine*

109   *spatial planning* (31.5 %) (Fig. 1). Other HEAs were less represented in the scientific literature,

110   with *systematic conservation planning*, *adaptive management* and *integrative management*

111   referred to in 16.4 %, 13.7 % and 8.5 % of the identified literature, respectively (Fig. 1). Overall,

112   few studies have considered multiple HEAs simultaneously, with 39 articles having the highest

113   overlap between *ecosystem-based management* and *marine spatial planning*. When analyzing the

114   keywords that were used in the reviewed articles, the most prevalent HEAs were "ecosystem-

115   based management" and "marine spatial planning". Another common keyword was "marine

116   protected areas", highlighting the relatively common use of this tool in marine conservation

117   programs.

118   The results show that HEAs were rarely discussed before 2006, and the number of HEA articles

119   peaked in 2013, 2014 and 2018 (Fig. 1). Overall, there was a steady increase in the number of

120   HEA articles since 2000. This is particularly true for marine HEAs where the number of studies

121   increased notably two years after the development of the Aichi Biodiversity Targets in 2010

122   (Fig. 1). This increase after 2012 appears to be largely driven by a rise in the number of

123   *ecosystem-based management* and *marine spatial planning* studies, which is likely a reflection of

124   the time required for Aichi-related frameworks to be implemented in research supporting the

125   management of socio-ecological systems (e.g. White et al., 2010).

126   Of all the studies on HEAs, only 12 specifically used the term *Aichi Targets*, representing 2.4 %

127   of the papers originally identified (Table 2). This is a low proportion of HEAs contributing to the

128   Strategic Plan for Biodiversity, even if we acknowledge that a study does not need to focus on a

129   specific Target to allow a contribution. In addition, nine studies explicitly considered Targets in

130   their research objectives (Table 2). The most frequently mentioned Aichi Biodiversity Target

131   was Target 11, which aims for the conservation of 10 % of coastal and marine areas by 2020

132   (Secretariat of the CBD, 2010). This Target is one of the few that specifically identifies

133   quantitative thresholds for protected areas (Harrop, 2011), which supports the development of

134   well specified and measurable objectives and tools such as simple, measurable, accurate,

135   realistic, time-bound indices (SMART). HEAs could use SMART objectives, although there are

136   few examples of their use in this context (Ehler, 2017). Specifying SMART objectives can be a

137   difficult task, but their measurable component can highlight successful accomplishment of

138   expected thresholds (Ehler, 2017; and references therein). Many studies selected in our literature

139   review evaluated progress and developments of marine protected areas (e.g. Amengual &

140   Alvarez-Berastegui, 2018; Jantke et al., 2018; Rees et al., 2018). Target 11 has also been used to

141   evaluate case studies (Diz et al., 2018), and to identify the sustainable use of specific marine

142   protected areas as part of workshops and wider consultations (Johnson et al., 2014; Sarker et al.,

143   2019). Other selected studies considered either a specific Aichi Biodiversity Target, such as

144   Target 12 in Davidson & Dulvy (2017) or Target 19 in Lagabrielle et al. (2017), or multiple

145   Targets, such as Targets 1, 3, 6, and 17 in Cisneros-Montemayor, Singh & Cheung (2018) or

146   Targets 6, 10, 11, and 12 in Davies et al. (2017) (Table 2). Five articles did not use *Aichi Targets*

147   in their specific objectives, but were included to set the wider context of the article (e.g.

148   Lagabrielle et al., 2014; Yamakita et al., 2015; Davidson & Dulvy, 2017; Davies et al., 2017;

149   Novaczek et al., 2017) (Table 2).

150

151   2.3.   Linking HEAs and the Strategic Plan for Biodiversity

152   Strategic Goals have been identified by the CBD as the steps necessary to safeguard biodiversity

153   by 2020 (Fig. 2A). These Goals include mainstreaming biodiversity across government and

154   society (Goal A), reducing direct pressures on biodiversity (Goal B), improving the status of

155   biodiversity (Goal C), enhancing benefits from biodiversity and ecosystem services (Goal D) and

156   enhancing implementation of the established measures (Goal E) (Secretariat of the CBD, 2010).

157   Aichi Biodiversity Targets have been set within each Goal, with specific objectives or

158   quantitative thresholds to reach (Fig. 2B). Our literature review gathered a large number of HEA

159   studies where a few referred to Targets in their objectives and methods (Table 1). Collectively,

160   we found that these studies have focussed on eight Targets, with five being specified as

161   objectives of the study (Table 2, Fig. 2C). This provides examples of how HEAs can contribute

162   to the Strategic Plan for Biodiversity while also providing feedback to reach specific Targets

163   (Fig. 2B-C). We will discuss some examples of these relationships in more detail in the section

164   below.

165   Modern sustainable development objectives include minimizing cross-scale human impacts on

166   biodiversity; concurrently, management plans are increasingly integrating social and economic

167   dimensions (IPCC, 2014; Steffen et al., 2015). Thus, by also considering these same dimensions,

168   HEAs explicitly include stakeholder involvement, public consultations or social initiatives,

169   which is in accordance to Target 1. When made available to the public, the use of a whole-

170   system approach within HEAs, in order to embrace ecosystem complexity, can raise awareness

171   about biodiversity (Palerm, 2000; Portman, 2009; Jarvis et al., 2015). Implementation of

172   conservation actions are usually complicated due to the variety of people concerned and the

173   commercial interests of the different stakeholders (Margules & Pressey, 2000), but also because

174   marine settings are particularly challenging, as stakeholders and objectives tend to be less well-

175   defined (Cisneros-Montemayor, Singh & Cheung, 2018). HEAs that take into account the natural

176   variability of ecosystems, such as adaptive management or ecosystem-based management,

177   should include social and political involvement (Stankey, Clark & Bormann, 2005).

178   HEAs should also favor whole-system approaches to prioritize management actions based on

179   ecosystem services, which relates to human use of environments (Carpenter et al., 2009; Chan &

180   Ruckelshaus, 2010; Kareiva et al., 2011; Queiroz et al., 2015). Cumulative impact assessments,

181   for example, focus on drivers of change and mechanistic pathways of impact in order to

182   prioritize management efforts and take into account ecosystem services and thus, socio-economic

183   dimensions (Brown et al. 2013, Cook et al. 2014; Cisneros-Montemayor, Singh & Cheung,

184   2018). These approaches can be linked with Target 3's objectives to decrease negative effects on

185   biodiversity and encourage conservation and sustainable use of biodiversity.

186   Target 6 states that fish and invertebrate stocks and aquatic plants are managed and harvested

187   sustainably, legally, and applying ecosystem-based approaches, so that overfishing is avoided,

188   recovery plans and measures are in place for all depleted species, fisheries have no significant

189   adverse impacts on threatened species and vulnerable ecosystems, and the impacts of fisheries on

190   stocks, species and ecosystems are within safe ecological limits. HEAs, such as ecosystem-based

191   management, resource management and adaptive management (along with all the processes

192   linked to theses approaches) will provide the tools to a better understanding of the species,

193   stocks, and habitats as well as their interactions in ecosystems (Arkema, Abramson & Dewsbury,

194   2006). These tools may be applied to a variety of concrete case studies, ranging from the

195   conservation of marine mammals to coral reef protection (Maggs, Mann & Cowley, 2013;

196   Authier et al., 2017), but also to discuss the adequacy and performance of management strategies

197   (Johnson et al., 2014; Cisneros-Montemayor, Singh & Cheung, 2018).

198   With the aim of improving the status of biodiversity, governments and companies are required to

199   enforce measures to safeguard ecosystems and all components therein (Secretariat of the CBD,

200   2010). In this context, HEAs can provide tools to accurately predict ecosystem consequences for

201   systems threatened by multiple drivers of change (Nilsson & Dalkman, 2001). For example, for

202   Target 11 and the conservation of marine and coastal areas, HEAs have a direct contribution by

203   being related and concerned with management, planning, and conservation. HEAs can also be

204   helpful in the identification and assessment of threats by being able to manage the multiple and

205   simultaneous drivers of change and stress.

206   The implementation of plans and strategies through participatory actions, such as proposed in

207   Target 17, requires the production of concrete tools to manage environmental use. The correct

208   implementation of HEAs can support the development of ecological indices to integrate different

209   ecosystem components in a coherent methodology, since the need for operational tools within

210   management plans has been highlighted (Arkema, Abramson & Dewsbury, 2006; Cisneros-

211   Montemayor, Singh & Cheung, 2018). In fact, these types of assessments are better undertaken

212   when they are done strategically and expressed in a measurable way, e.g. using SMART

213   objectives (Jones 2016).

214

215

216   **3.   Research priorities**

217   HEAs should integrate every component of the studied ecosystems. However, logistical,

218   technical and monetary considerations may limit the feasibility of such a goal. Nonetheless,

219   'partial' HEAs are often more valuable than specific environmental assessments (Jones, 2016).

220   The complexity and breadth of knowledge needed for 'full' HEAs makes them exceedingly

221   difficult to implement, which may likely explain the relatively small number of studies found

222   applying holistic approaches to ecosystem management (Table 1). In order to achieve the goals

223 set by the Strategic Plan for Biodiversity, there is a need to develop management actions beyond

224 2020 (Secretariat of the CBD, 2014). Discussions to identify the strategic direction for a post-

225 2020 global biodiversity framework are taking place (e.g. IX Trondheim Conference on

226 Biodiversity), and the need for holistic management actions for a sustainable environment has

227 been highlighted.

228 With this in mind, research priorities for the application of HEAs in marine environments were

229 identified during the 4th World Conference on Marine Biodiversity as part of a mentoring

230 program. Participants worked individually to identify research priorities before the conference, in

231 order to provide a comprehensive list for the conference. This list was then used by participants

232 to collectively curate a list of the top research priorities. This selection was discussed with

233 conference attendees through panel discussions during the conference and comments were used

234 to refine priorities post-conference. This process yielded a list of five research priorities (Fig.

235 2D). The steps to undertake, in order to develop and promote the use of holistic approaches for

236 marine biodiversity conservation, are discussed below.

237

238   3.1.   Priority I: Expand the use of holistic approaches in environmental assessments

239 Marine biodiversity spans different levels of biological organization (Hagen et al., 2012). The

240 various biological components of a given ecosystem are continuously interacting with their

241 environment within complex ecological networks. However, many environmental assessments

242 focus on a single species or a single component of the ecosystem, overlooking important abiotic

243 and biotic interactions that significantly affect the way organisms interact with their environment

244 and mediate ecosystem functioning (Crain, Kroeker & Halpern, 2008; Bulleri, 2009; van der Plas

245 2019). Therefore, accurately assessing ecological functioning of marine ecosystems and their

246 environmental, social and economic sustainability requires a holistic approach (Burton et al.,

247 2014; Ma et al., 2017).

248 Characterization of marine biodiversity and ecosystem functioning can be achieved through

249 theoretical, numerical, experimental or monitoring approaches (Costello et al., 2017; Eriksen et

250 al., 2018). Emerging environmental DNA techniques consisting of DNA metabarcoding and

251 metagenomics (e.g. Thomsen & Willerslev, 2015) offer potentially powerful new tools to

252 monitor marine biodiversity and detect new species introductions. This allows reduced

253   investment in traditional taxonomic techniques and biodiversity sampling and provides new

254   opportunities to assess challenging and remote locations (Brown et al., 2016; Lacoursière-

255   Roussel et al., 2018). Moreover, scientific research vessels now deploy vast arrays of equipment

256   and gears simultaneously to answer increasingly complex research questions about whole

257   ecosystems rather than as individual components (e.g. Pesant et al., 2015). These new emerging

258   methodologies and technologies can complement current holistic approaches such as cumulative

259   effects assessments (Halpern et al. 2008; 2015) or systematic conservation planning (Margules &

260   Pressey 2000; Ball, Possingham & Watts, 2009; Daigle et al. 2019). Managers increasingly

261   recognize the need to shift towards holistic approaches to generate informed actions more

262   inclusive of the relationships between ecosystem components than those obtained by traditional

263   single-species efforts (e.g. Manley et al., 2004; Beever, 2006).

264   The use of HEAs is relevant to all Targets within Goals B and C. In particular, expanding the use

265   of holistic approaches could benefit Target 11's conservation objectives and perspectives by

266   considering the complexity of the ecosystems (Rees et al., 2018).

267

268   3.2.   Priority II: Standardize HEAs vocabulary

269   What is a "driver of change", and when does it become a "stressor"? What constitutes an

270   "impact"? The need to adopt a common vocabulary is especially important for multidisciplinary

271   approaches in which communication between actors with a variety of backgrounds is often

272   impeded by semantics (Holt et al. 2011). For example, the scientific community frequently uses

273   the expression "cumulative effects assessment", but the underlying principles are often poorly

274   understood, which may impact the interpretation of these assessments. Along with the definition

275   of a concept, the origins behind the terminology must be explored and the terms standardized

276   prior to their application across disciplines (Judd, Backhaus & Goodsir, 2015).

277   Analytical frameworks such as DPSIR (Drivers, Pressures, State, Impact, Response) models are

278   useful for HEAs if all of the included elements are well defined and consistent (Kelble et al.,

279   2013). However, Lewison et al. (2016) and Gari et al. (2014) found that despite the widespread

280   application of individual terms across disciplines and projects, there is still no consensus on the

281   definitions of "pressure" and "impact". These different interpretations decrease the

282   understanding and operationalization of HEAs across scientists, stakeholders, and decision

283   makers (Gari et al., 2014). The strengths of DPSIR frameworks, such as the capacity to describe

284   linkages between human activity and environmental issues, encourage transdisciplinary research

285   and will benefit many disciplines once its components are clarified (Kelble et al., 2013; Lewison

286   et al., 2016).

287   While vocabulary standardization does not contribute directly to a specific Aichi Biodiversity

288   Target, it will promote the applicability of HEAs by facilitating communication between actors,

289   which could ultimately be advantageous to all Strategic Goals and Aichi Biodiversity Targets.

290

291   3.3.   Priority III: Enhance data collection, sharing, and management practices

292   The application of HEAs is highly dependent on efficient data collection, sharing, and

293   management. However, constructing large datasets for holistic approaches is a challenging

294   endeavour whose complexity is compounded by decentralized digital infrastructure and

295   heterogenous practices (Wilkinson et al., 2016). To this end, we have identified three steps to

296   promote data collection, sharing, and management efficiency for use in HEAs.

297   Firstly, it is imperative to develop proper mechanisms to incentivize researchers to share their

298   data publicly. In order to accelerate scientific discoveries and optimize research investments,

299   many scientific journals and governmental agencies have initiated strong policies to promote

300   public data archiving (Tenopir et al., 2011; Poisot, Mounce & Gravel, 2013; Roche et al., 2015).

301   Regardless, many researchers remain reluctant to share their data publicly (Tenopir et al., 2011;

302   Hampton et al., 2013; Roche et al., 2014), highlighting the lack of widespread mechanisms to

303   give proper scientific value to data products (Wilkinson et al., 2016).

304   Secondly, our digital infrastructure should be improved so that data needed for HEAs are easily

305   and openly accessible to all practitioners, scientists, and the public. We recommend adhering and

306   promoting the FAIR Data Principles, which states that data must be Findable, Accessible,

307   Interoperable, and Reusable (Wilkinson et al., 2016; Tanhua et al., 2019). This emerges as a

308   crucial step to foster proper data management practices and to provide quality data and

309   knowledge relevant to HEAs. Open-access data resources such as the Ocean Biodiversity

310   Information System (OBIS, 2019) and the Global Biodiversity Information Facility (GBIF,

311   2019) exemplify excellent and easily accessible sources that can be used by researchers to share

312   their data.

313   Finally, we should strive for global standardization of ocean practices. Defining clear standards

314   and protocols will favour compatibility and pave the way towards efficient HEAs by facilitating

315   the aggregation of local and regional datasets into large, holistic datasets. Initiatives that seek

316   such standardization in practices, such as the Essential Ocean Variables from the Global Ocean

317   Observing System (GOOS, 2019) and the Ocean Best Practices repository (OBP, 2019) from the

318   International Oceanographic Data and Information Exchange, should thus be highly promoted.

319   Addressing these three steps will enhance data and protocol management, along with knowledge

320   transfer and interoperability, which are necessary for efficient and robust HEAs. This will, in

321   turn, facilitate education and outreach, management and conservation actions, evaluation of

322   ecosystem services, data sharing and capacity building, which are the cornerstones of the

323   Strategic Plan for Biodiversity.

324

325   3.4.   Priority IV: Consider ecosystem spatio-temporal variability

326   Ecosystem studies widely recognize the importance of spatial and temporal scales, as they

327   influence ecosystem components (e.g. fauna, flora), and characterize ecological processes

328   (Legendre, 1993, Hagen et al., 2012; Pittman, 2017). Organism-environment interactions occur

329   across a variety of spatio-temporal scales (e.g. Legendre & Gauthier, 2014; Kraan et al., 2015;

330   Yeager et al. 2017; Ryo et al. 2019), but only few HEA studies have acknowledged the need to

331   consider these variations, for example by comparing different seasons or locations (e.g. de la

332   Vega et al., 2018a; 2018b). Despite available methodologies to investigate spatio-temporal

333   patterns within ecosystems (e.g. Baselga, 2010; Legendre & Gauthier, 2014), we are unaware of

334   environmental assessments that investigated multiple spatio-temporal structures concurrently in

335   marine environments.

336   In addition to the organism-environment interactions, spatio-temporal structures can also affect

337   human activities in an economic context. This can be seen with fisheries management, where

338   activities occur across multiple spatio-temporal scales by involving single boat and fleet

339   activities and managed to exploit targeted resources most efficiently (Hilborn, 2007; Watson et

340   al., 2018). For example, tuna fishermen may be three times more profitable if fishing on strong

341   oceanographic fronts (*i.e.* Lagrangian coherent structures; Watson et al., 2018). This implies that

342   the effects of a physical feature of the water column can trickle through the local food web,

343   ultimately affecting fisheries profitability at the spatial and temporal scale of the physical feature.

344   Human activities can interact directly and indirectly with a variety of natural drivers, such as

345   shear stress, storms or currents, at different spatio-temporal scales (van Denderen et al., 2015;

346   Watson et al., 2018). These interactions may trigger biodiversity responses that consequently

347   appear at different levels of organization, influencing both faunal composition and functions that

348   ultimately impact ecosystem functions and services. In order to develop successful conservation

349   actions, HEAs require further understanding of the spatio-temporal structure of ecosystems and

350   the scales of variability of related ecological patterns and processes, in order to adapt to their

351   variability.

352   With respect to the Aichi Biodiversity Targets, assessing scales of spatio-temporal variability

353   through HEAs will assist in reducing the impacts of human activities on ecosystems and species

354   (Goal B), and to enhance management strategies to improve the status of critical areas (Goal C).

355

356   3.5.   Priority V: Integrate ecosystem services

357   The concept of "ecosystem services" has initiated the creation of a set of principles to be used by

358   researchers and managers to support ecosystem conservation initiatives (de Groot, Wilson &

359   Boumans, 2002; Beaumont et al., 2007). Ecosystem services are the benefits that humans gain

360   from the natural environment (MEA, 2005). They include provisioning (e.g. production of food

361   or raw materials), regulating (e.g. water purification, carbon sequestration), supporting (e.g. soil

362   production, primary production) and cultural services (e.g. aesthetic, recreation) (Beaumont et

363   al., 2007; Fisher, Turner & Morling, 2009; Atkins et al., 2011; Balmford et al. 2011). Such

364   services may be used to find compromises between providing a hospitable environment for

365   human populations, maintaining ecosystem patterns, and processes within a sustainable range of

366   variation (Beaumont et al., 2007; Cardinale et al., 2012; Norris, 2012). Because ecosystem

367   services consider multiple aspects of the ecosystems within integrative frameworks, they will be

368   highly relevant in HEAs.

369 Management and consideration of each ecosystem service category is often not equivalent within

370 policy, resulting in a possible mismatch with environmental assessment in terms of spatio-

371 temporal scales (Srivastava & Vellend, 2005; Cardinale et al., 2012). In order to use ecosystem

372 services for biodiversity and ecosystem conservation, many ongoing discussions between

373 stakeholders are seeking a common ground in their respective objectives and agendas (Seddon et

374 al., 2016; Dee et al., 2017a). For example, Holt et al. (2011) quantified the types of services most

375 valued by the local community and stakeholders in a coastal wetland and established the

376 legislative mismatches that exist for protecting those ecosystem processes and functional that are

377 necessary to support the valued benefits. This represents an important step towards integration of

378 ecosystem services in frameworks like HEAs. While we acknowledge the complexity of these

379 discussions and the ongoing research on the topic (e.g. Paterson et al., 2011; Langhans et al.,

380 2019), we emphasize that the integration of ecosystem services by stakeholders and within HEAs

381 will provide a great tool for the Strategic Plan for Biodiversity. To this end, approaches

382 considering ecosystems through network theory may be a great tool to consider the complexity

383 of ecosystems with the plurality of human influences and services (Dee et al., 2017b).

384 Considering ecosystem services in HEAs will benefit the safeguarding of ecosystems and the

385 maximization of benefits as stated in Goal D. The literature review detected an absence of HEA

386 studies specifically including Targets of this Goal, which highlights the need to better link HEAs

387 and ecosystem services.

388

389

390 **4. Conclusion**

391 HEAs have the potential to enhance marine conservation and management initiatives

392 significantly beyond 2020. The use of HEAs has been increasing steadily over the past decade

393 and is likely related to the establishment of the Strategic Plan for Biodiversity. To date, only a

394 few studies refer to specific Aichi Biodiversity Targets in their research objectives. If included,

395 HEAs could improve ecological research related to these Targets in a variety of ways: from the

396 development of ecological indices and increased understanding of species-ecosystem interaction,

397 to the provision of tools for the prediction of multiple drivers of change and helping the

398 establishment of frameworks for citizen science. All these actions could simultaneously increase

399   understanding of ecosystem complexity in management schemes and decision-making in order to

400   achieve biodiversity goals.

401   We proposed five research priorities that could increase the effectiveness of HEAs in attaining

402   the Aichi Biodiversity Targets, with respect to their current state of completion. Holistic

403   approaches must appropriately assess the ecological functioning of marine ecosystems and their

404   environmental, social and sustainable economic development. There is a need to standardize the

405   vocabulary used for environmental assessments. Data collection needs to integrate system

406   complexity and data management needs to follow recognized international standards. Marine

407   biodiversity monitoring must consider single and multiple ecosystem components, must observe

408   variability at different scales and should link biodiversity conservation to ecosystem services to

409   support their sustainable uses.

410   Considering these priorities will help raise the value of HEAs to managers, ensuring greater

411   accuracy and predictive power in environmental management, and could greatly help preparation

412   of the work beyond the Strategic Plan for Biodiversity.

413

414

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424

425

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Figure 1

Number of articles per year adopting a Holistic Environmental Approach (HEA) identified in *ISI Web of Knowledge.*

(A) Number of HEA studies conducted in terrestrial, freshwater and marine environments (light grey), including studies focusing only on marine environments (dark grey). (B) Prevalence of each HEA within studies targeting marine environments only. Searches queried the title, abstract and keywords of peer-reviewed articles. Publication of the Aichi Biodiversity Targets in 2010 is represented by the black dashed vertical line.

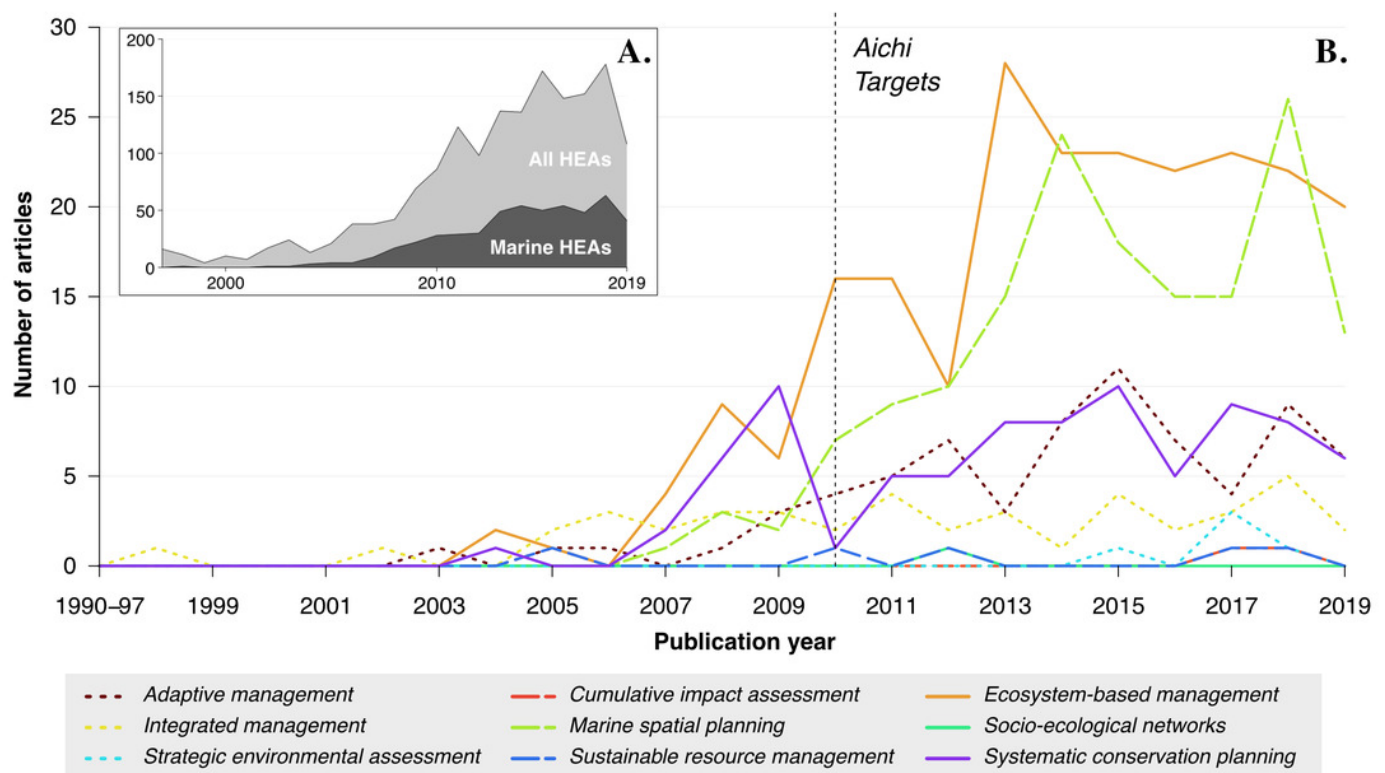
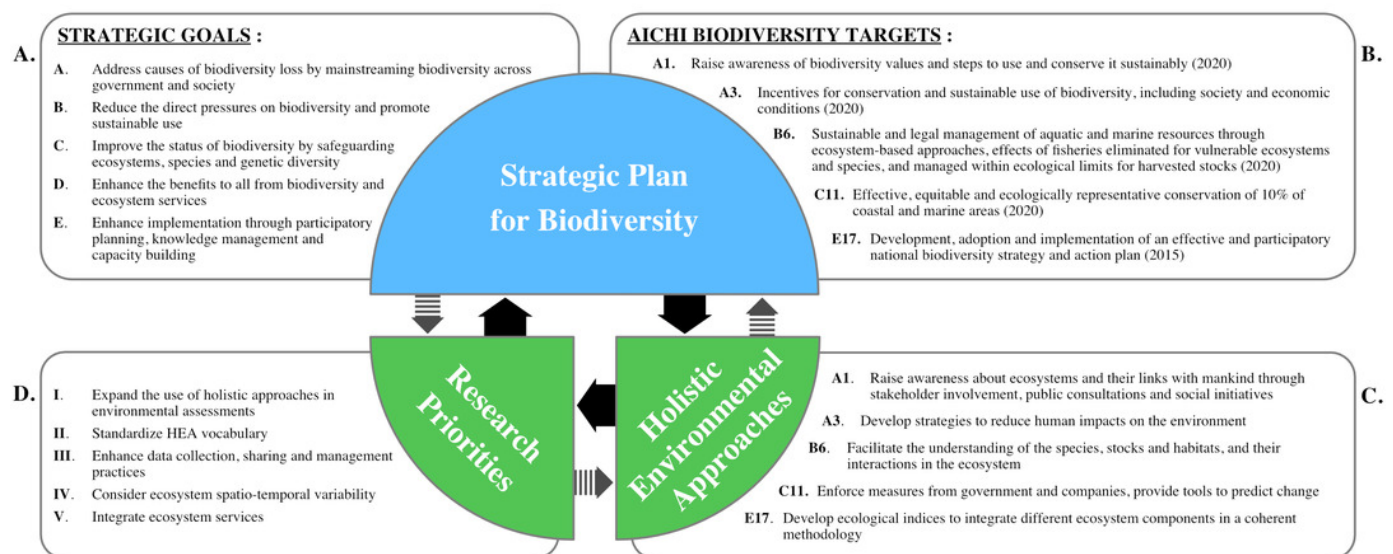



Figure 2

Conceptual diagram of interactions and relationships between the Strategic Goals (A), the Aichi Biodiversity Targets (B), Holistic Environmental Approaches (C), and the identified research priorities (D).

Targets have been summarized from Secretariat of the CBD (2010), and the letter before their number corresponds to the Goal to which they belong. Solid arrows represent direct relationships between sections, and dashed arrows represent secondary feedback.

Search terms used in *ISI Web of Knowledge* to characterize the relevance of Holistic Environmental Approaches (HEAs) to achieving the Strategic Plan for Biodiversity.

The different queries were limited from January 1990 to July 2019. Queries and search terms have been formatted with a regular expression syntax (REGEX) structured with conditional statements in italics, except for queries 2.x which have searched only for one type of HEA at a time.

ID	Query	Articles
1	Criteria *AND* HEAs	1,648
2	Criteria *AND* HEAs *AND* "marine"	505
2.1	Adaptive management	69
2.2	Cumulative impact assessment	2
2.3	Ecosystem-based management	223
2.4	Integrated management	43
2.5	Marine spatial planning	159
2.6	Social-ecological network	1
2.7	Strategic environmental assessment	5
2.8	Sustainable resource management	5
2.9	Systematic conservation planning	83
3	Criteria *AND* HEAs *AND* "marine" *AND* "Aichi"	12

1   Criteria: (ecolog* *OR* ecosystem *OR* environment* *OR* habitat *OR* species) *AND* "biodiversity"
2   HEAs: "adaptive management" *OR* ("cumulative effect* assessment" *OR* "cumulative impact*
3   assessment") *OR* "ecosystem.based management" *OR* ("integrated management" *OR* "integrative
4   management") *OR* "marine spatial planning" *OR* "social.ecological network*" *OR* "strategic
5   environmental assessment" *OR* "sustainable resource management" *OR* "systematic conservation
6   planning"

Links between articles adopting a Holistic Environmental Approach (HEA) obtained for Query 3 of the literature review and the Aichi Biodiversity Targets.

ID	Article	Type of HEA considered	Targets considered	Targets as objectives?
1	*Amengual & Alvarez-Berastegui (2018)*	Marine spatial planning	11	Yes
2	*Cisneros-Montemayor, Singh & Cheung (2018)*	Adaptive management	1, 3, 6, 17	Yes
3	*Davidson & Dulvy (2017)*	Systematic conservation planning	11, 12	No
4	*Davies et al. (2017)*	Systematic conservation planning	6, 10, 11, 12	No
5	*Diz et al. (2018)*	Marine spatial planning	11	Yes
6	*Jantke et al. (2018)*	Systematic conservation planning	11	Yes
7	*Johnson et al. (2014)*	Ecosystem-based management	6, 11	Yes
8	*Lagabrielle et al. (2014)*	Marine spatial planning	11, 19	No
9	*Novaczek et al. (2017)*	Adaptive management	11	No
10	*Rees et al. (2018)*	Marine spatial planning	11	Yes
11	*Sarker et al. (2019)*	Integrated management	11	Yes
12	*Yamakita et al. (2015)*	Strategic environmental assessment	11	No