

Alma Mater Studiorum Università di Bologna  
Archivio istituzionale della ricerca

A global approach to mapping the environmental risk of harbours on aquatic systems

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

*Published Version:*

Valdor, P.F., Gómez, A.G., Steinberg, P., Tanner, E., Knights, A.M., Seitz, R.D., et al. (2020). A global approach to mapping the environmental risk of harbours on aquatic systems. MARINE POLICY, 119, 1-10 [10.1016/j.marpol.2020.104051].

*Availability:*

This version is available at: <https://hdl.handle.net/11585/762373> since: 2020-09-25

*Published:*

DOI: <http://doi.org/10.1016/j.marpol.2020.104051>

*Terms of use:*

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).  
When citing, please refer to the published version.

(Article begins on next page)

This is the final peer-reviewed accepted manuscript of:

**Paloma F. Valdor, Aina G. Gómez, Peter Steinberg, Edwina Tanner, Antony M. Knights, Rochelle D. Seitz, Laura Airoidi, Louise B. Firth, Christos Arvanitidis, Massimo Ponti, Eva Chatzinikolaou, Paul R. Brooks, Tasman P. Crowe, Alison Smith, Gonzalo Méndez, Aida Ovejero, Abilio Soares-Gomes, John A. Burt, Catriona MacLeod, José A. Juanes (2020). A global approach to mapping the environmental risk of harbours on aquatic systems. *Marine Policy*, 119**

The final published version is available online at  
<https://dx.doi.org/10.1016/j.marpol.2020.104051>

Rights / License:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

*This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>)*

***When citing, please refer to the published version.***

## A global approach to mapping the environmental risk of commercial harbours on aquatic systems

Paloma F. Valdor<sup>a</sup>, Aina G. Gómez<sup>a,m</sup>, Peter Steinberg<sup>b,c</sup>, Edwina Tanner<sup>b</sup>, Antony M. Knights<sup>d</sup>, Rochelle D. Seitz<sup>e</sup>, Laura Airoidi<sup>f</sup>, Louise B. Firth<sup>d</sup>, Christos Arvanitidis<sup>g</sup>, Massimo Ponti<sup>f</sup>, Eva Chatzinikolaou<sup>g</sup>, Paul R. Brooks<sup>h</sup>, Tasman P. Crowe<sup>h</sup>, , Alison Smith<sup>e</sup>, Gonzalo Méndez<sup>i</sup>, Aida Ovejero<sup>i</sup>, Abilio Soares-Gomes<sup>j</sup>, John A. Burt<sup>k</sup>, Catriona MacLeod<sup>l</sup>, José A. Juanes<sup>a,\*</sup>

<sup>a</sup> Environmental Hydraulics Institute, Universidad de Cantabria - Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain, T:+34.942.20.16.16, [palomavaldor@gmail.com](mailto:palomavaldor@gmail.com), [aina.gomez@unican.es](mailto:aina.gomez@unican.es), [juanesj@unican.es](mailto:juanesj@unican.es)

<sup>b</sup> Sydney Institute of Marine Science, 19 Chowder Bay Rd, Mosman NSW 2088, Australia. [p.steinberg@unsw.edu.au](mailto:p.steinberg@unsw.edu.au), [Edwina.Tanner@sims.org.au](mailto:Edwina.Tanner@sims.org.au)

<sup>c</sup> School of BEES, University of New South Wales Sydney, NSW 20152, Australia, [p.steinberg@unsw.edu.au](mailto:p.steinberg@unsw.edu.au)

<sup>d</sup> School of Biological and Marine Sciences, University of Plymouth, Plymouth, U.K., [louise.firth@plymouth.ac.uk](mailto:louise.firth@plymouth.ac.uk), [antony.knights@plymouth.ac.uk](mailto:antony.knights@plymouth.ac.uk)

<sup>e</sup> Virginia Institute of Marine Science, William & Mary, Virginia, U.S.A., [seitz@vims.edu](mailto:seitz@vims.edu), [asmith@vims.edu](mailto:asmith@vims.edu)

<sup>f</sup> Department of Biological, Geological and Environmental Sciences and Interdepartmental Research Centre for Environmental Sciences, UO CoNISMa, University of Bologna, Via S. Alberto 163, 48123, Ravenna, Italy, [laura.airoidi@unibo.it](mailto:laura.airoidi@unibo.it); [massimo.ponti@unibo.it](mailto:massimo.ponti@unibo.it)

<sup>g</sup> Institute of Marine Biology, Biotechnology and Aquaculture Hellenic Centre for Marine Research, Attiki, Greece, [arvanitidis@hcmr.gr](mailto:arvanitidis@hcmr.gr), [evachatz@hcmr.gr](mailto:evachatz@hcmr.gr)

<sup>h</sup> UCD Earth Institute and School of Biology and Environmental Science, University College Dublin, Dublin, Ireland, [paul.brooks@ucd.ie](mailto:paul.brooks@ucd.ie); [tasman.crowe@ucd.ie](mailto:tasman.crowe@ucd.ie)

<sup>i</sup> UNESCO Chair in Sustainable Coastal Zone Management, University of Vigo, Vigo, Spain, [mendez@uvigo.es](mailto:mendez@uvigo.es), [aovejero@uvigo.es](mailto:aovejero@uvigo.es)

<sup>j</sup> Sediment Ecology Laboratory, Marine Biology Department, Federal Fluminense University, Rio de Janeiro, Brazil, [abiliosg@id.uff.br](mailto:abiliosg@id.uff.br)

<sup>k</sup> Center for Genomics and Systems Biology, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates, [john.burt@nyu.edu](mailto:john.burt@nyu.edu)

<sup>l</sup> Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Australia, [catriona.macleod@utas.edu.au](mailto:catriona.macleod@utas.edu.au)

<sup>m</sup> Balearic Islands Coastal Observing and Forecasting System (SOCIB), Parc Bit, Naorte, Bloc A 2º 3p, 07121 Palma de Mallorca, Spain

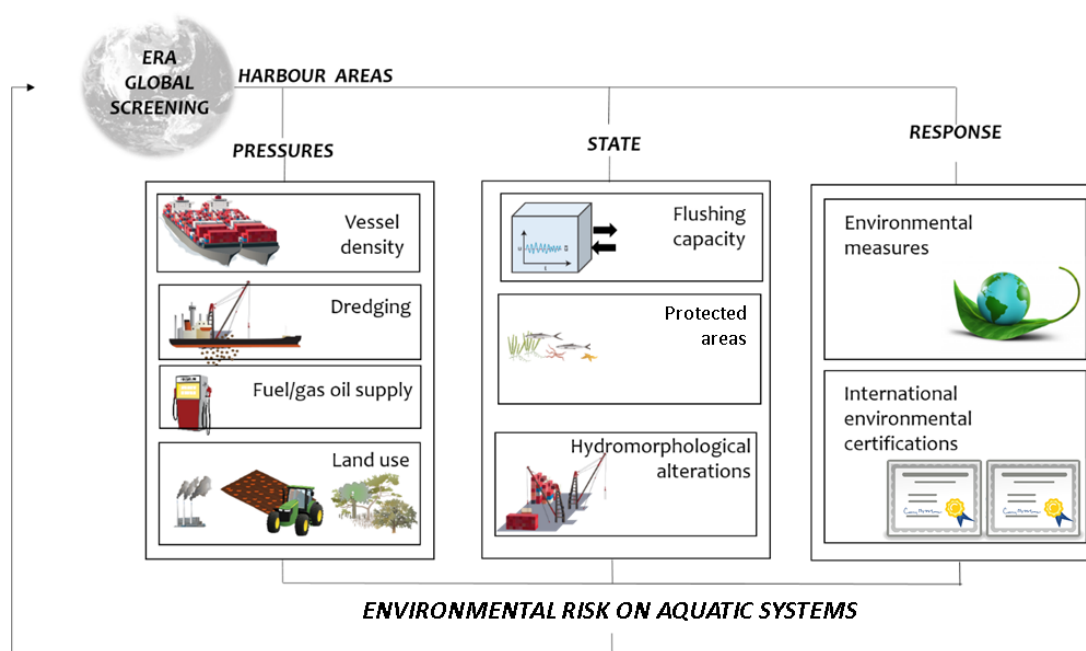
\*Corresponding author E-mail addresses: [juanesj@unican.es](mailto:juanesj@unican.es) (José A. Juanes)

# A global approach to mapping the environmental risk of harbours on aquatic systems

## Highlights:

- A method is proposed to assess the environmental risk of commercial harbours on aquatic systems.
- The method is a tool to identify the factors of risk on harbour aquatic systems
- Results obtained from 15 globally distributed harbours are analysed
- Towards the creation of a global atlas of environmental risk of harbours on aquatic systems

## Graphical abstract:



## Abstract:

The goal of this paper is to propose a screening method for assessing the environmental risk to aquatic systems in harbours worldwide. A semi-quantitative method is based on environmental pressures, environmental conditions and societal response. The method is flexible enough to be applied to 15 harbours globally distributed through a multinational test using standardised and homogenised open data that can be obtained for any port worldwide. The method emerges as a useful approach towards the foundation of a global

19 environmental risk atlas of harbours that should guide the harbour sector to develop a  
20 more globally informed strategy of sustainable development.  
21 **Keywords:** environmental risk assessment; global atlas; pressure-state-response model;  
22 harbour aquatic systems; harbour management; sustainable development.

## 24 1. INTRODUCTION

25 Shipping has an important role in moving about 90% of global trade, which is vital for the  
26 continuing and sustainable development of the world economy (ICS, 2018; 2019). The  
27 shipping sector is projected to continue to expand in the future with an estimated annual  
28 growth rate of 3.2% by 2017-2022 (UNCTAD, 2017). The relevance of this sector for world  
29 trade has placed this industry at the centre of a policy debate on globalisation, trade,  
30 development and environmental sustainability (UNCTAD, 2012). Harbours are continuing to  
31 expand to accommodate the infrastructure required to support growth in the shipping  
32 industry (UNCTAD, 2012). This growth increases the likelihood of environmental damage,  
33 which, to some extent, is being mitigated by harbour authorities embracing a sustainable  
34 development approach (EC, 2013). Shipping, alongside the many other marine activities,  
35 generates several threats of varying severity to marine ecosystems (Gómez et al., 2014;  
36 Knights et al., 2015; Valdor et al., 2017), and harbours themselves can be some of the most  
37 impacted habitats on Earth (Halpern et al., 2008).

39 The environmental sustainability of harbours needs to be focused on preventing the  
40 impoverishment of aquatic systems caused by pollution from commercial ships or other  
41 navigation activity. Harbours are guided and regulated by international legislation that aims  
42 to limit ecosystem exposure to harmful activities. International bodies, like the International  
43 Maritime Organisation (IMO), continue to develop legal frameworks to mitigate  
44 environmental harm as a result of commercial shipping (e.g. IMO, 2004; 2013; 2014 or  
45 Lethbridge, 1991), and they set the appropriate standards through international treaties and  
46 conventions. Others, such as the World Association for Waterborne and Transport

47 Infrastructure (PIANC), provide expert guidance (PIANC, 2019), recommendations (PIANC,  
48 2011) and technical advice (PIANC, 2020) on environmental issues related to both  
49 recreational and commercial navigation activity (Brolsma, 2010). The maintenance of high-  
50 quality aquatic systems (e.g. by preventing marine pollution) is a permanent and universal  
51 goal of these conventions, guidelines and the research developed by these international  
52 organisations. Consequently, water quality has been one of the top 10 environmental  
53 priorities of the harbour sector over last years (2003-2009) (ESPO-ECOPORTS, 2019).

54  
55 Scientific research that provides an evidence-based for decision-making related to  
56 environmental risk on harbour aquatic systems is conducted by projects like the World  
57 Harbour Project (WHP) ([www.worldharbourproject.org](http://www.worldharbourproject.org), Steinberg et al., 2016). This project  
58 enhances research and management across major urban harbours. To develop resilient  
59 urban harbours, a global network of collaborating scientists works on different topics such  
60 as ecological engineering (Strain et al., 2019), environmental management (Valdor et al.,  
61 2019), accessible syntheses and summaries of current knowledge (e.g. Juanes et al.,  
62 2020). Thus, research programs should be responsible in developing science and  
63 communicating findings in an accessible way to a wide range of users to facilitate the  
64 design of global strategies. We suggest that global strategies are needed to ensure that  
65 harbour managers worldwide are able to assess the environmental risk on aquatic  
66 systems using an easy-to-apply and versatile method. In this context, one of the main  
67 objectives of global strategies is to provide standardised methods to analyse risk. In this  
68 way, data among different harbours are comparable, and their management can be  
69 adjusted to the best available practices regarding limiting environmental risk.

70  
71 However, when global strategies are designed, the harbours' histories, the  
72 geomorphological and environmental contexts and the socio-economic settings are very  
73 different across the world (Steinberg et al., 2016) and thus may affect approaches to  
74 environmental management. In that context, the Environmental Risk Assessment (ERA)

178  
179  
180 75 arises as a general management tool that is used worldwide to assess potential effects on  
181  
182 76 the environment due to the exposure to disturbing agents derived from different human  
183  
184 77 activities (e.g. fishery, industry, urban, agricultural or harbour activities, among others)  
185  
186 78 (AENOR, 2008; Hope, 2006; Smith et al., 2007; Samhouri and Levin, 2012; Valdor et al.,  
187  
188 79 2016). Using the ERA approach, the potential effects of environmental hazards on the  
189  
190 80 quality of aquatic systems in harbour areas have been widely studied (e.g. Ronza et al.,  
191  
192 81 2006; Grifoll et al., 2010; Gómez et al., 2015; Ondiviela et al., 2012; Parra et al., 2018), and  
193  
194 82 methods to assess the environmental risks of harbour activities have been proposed (e.g.  
195  
196 83 Gómez et al., 2015; Juanes et al., 2013; Ondiviela et al., 2012; Puig et al., 2015; Valdor et  
197  
198 84 al., 2016). However, worldwide studies to assess the environmental risk of harbour activities  
199  
200 85 on aquatic systems to support global strategies, such as Global Sustainable Development  
201  
202 86 Goals (United Nations, 2015), have not been conducted.

203  
204 87 Harbours around the world implement different environmental management methods that  
205  
206 88 make use of different approaches to the characterisation of systems, use different analytical  
207  
208 89 tools and databases, thus making it challenging to obtain standardised quantitative data  
209  
210 90 globally (PIANC, 2019). For this reason, qualitative and semi-quantitative data analyses are  
211  
212 91 more suitable alternatives when conducting an ERA study at a global scale (Gómez et al.,  
213  
214 92 2019). Moreover, parameters, indicators, and assessment criteria should be carefully  
215  
216 93 selected to integrate the singularities of each specific harbour (Darbra et al., 2005; Gupta et  
217  
218 94 al., 2005). We suggest that, at the same time, the simplicity and low computing cost of the  
219  
220 95 method should allow for wider applicability to harbours of different sizes, hydrodynamic  
221  
222 96 characteristics, harbour uses and pressures or resources to assess environmental  
223  
224 97 challenges.

225 98  
226  
227 99 The goal of this paper is to propose a method for mapping the assessment of the  
228  
229 100 environmental risk of harbours on aquatic systems. This method will be: i) flexible enough  
230  
231 101 to be applied to any harbour worldwide; ii) open-data dependent; and iii) implemented to lay  
232  
233 102 the foundation to create a global atlas of environmental risk on aquatic systems of harbours.  
234  
235  
236

237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295

103 The proposed method is tested by applying it to 15 harbours spread across five continents  
104 worldwide. The main contributions of this study are: (i) the development of a standard and  
105 unified ERA method to assess environmental risk of harbour activities worldwide on aquatic  
106 systems (Section 2); (ii) the implementation of the ERA method in 15 harbours around the  
107 world (Section 3); and (iii) the discussion of the proposed method and the results obtained  
108 in the implementation (Section 4).

## 109 **2. MATERIALS AND METHODS**

110 The semi-quantitative method providing an assessment of environmental risk on aquatic  
111 systems is based on the Pressure-State-Response (PSR) model defined by Gómez et al.  
112 (2019) for marinas. The method comprises the following three steps: i) identification of  
113 harbours and data collection; ii) estimation of the risk factors (environmental pressures of  
114 harbour activities on the aquatic system, environmental conditions and management  
115 responses); and iii) assessment of environmental risk.

### 116 **2.1 Identification of harbours**

117 Harbours are classified based on the typologies defined by the US National Geospatial-  
118 Intelligence Agency (2015) into: i) coastal natural harbours are harbours that are sheltered  
119 from the wind and sea due to their location within a natural coastline or occur in the protective  
120 lee of an island, cape, reef or other natural barrier, or harbours that are located along a river;  
121 ii) coastal breakwater harbours are harbours located behind a human-made breakwater that  
122 are constructed to provide shelter or supplement inadequate shelter already provided by  
123 natural resources; and iii) natural river harbours are harbours in which slips for vessels have  
124 been excavated in the banks obliquely or at right angles to the axis of the stream.

125 For this study, general data, hydro-morphological characteristics and environmental  
126 management information was gathered globally at all 15 harbours through a standardised  
127 form (Supplementary Data. Appendix A) and through other sources of information (e.g.,  
128 official harbour webpages).



## 2.2 Estimation of environmental risk

Environmental risk assessment at the harbour level was based on three factors: i) Pressures from human activities exerted on the environment; ii) State, or the environmental conditions that relate to the quality of the environment; and, iii) Response, or the extent to which the harbour responds to environmental concerns (OECD, 2003) (Eq.1).

Accordingly and based on Gómez et al., (2019), environmental risk of harbours on aquatic systems was estimated through the following formulas:

$$R_i = P_{ti} \times S_{ti} + R_{si} \quad (\text{Eq. 1})$$

$$R_i = (NV_i + HS_i + HO_i + CD_i) \times (SU_i + EV_i + NA_i) + (AM_i + AI_i) \quad (\text{Eq. 2})$$

Where  $R$  is the environmental risk,  $P_t$  is the Pressure,  $S_t$  is the State and  $R_s$  is the Response of an  $i$  harbour. Pressure is estimated considering the navigation activity (NV), the harbour services (HS), the harbour operation (HO) and the coastal development around the harbour (CD). While, State is estimated by combining the susceptibility (SU), the ecological value (EV) and the naturalness (NA). Finally, Response was estimated through the adopted measures (AM) and the Adopted Instruments (AI).

Estimation of environmental risk was evaluated using a semi-quantitative assessment criteria that was based on a combination of specific indicators, representative of a number of selected parameters for each factor (Table 1).

Table 1. Parameters, indicators, metrics and criteria assessment to estimate each environmental risk factor. (i: a specific harbour; max: maximum value obtained for a parameter considering all harbours under study; ISO: International Organisation for Standardisation; EMAS: Eco-Management and Audit Scheme; PERS: Port Environmental Review System). Unless specifically indicated by appropriate references to the source paper indicators were originally developed here.

Factor	Parameter	Indicator and metric (units)	Criteria assessment
<b>Pressures</b>	<b>Navigation Activity (NV)</b>	<b>Density of trade vessels</b> (vessels per year/m <sup>2</sup> ) by dividing vessels per year by the surface water area where the harbour activities take place.	$NV_i/NV_{\max}$ [0-1]

	<b>Harbour Services (HS)</b>	<b>Harbour services:</b> presence (1) or absence (0) of fuel oil and diesel oil supplies, major repair services and dangerous/hazardous goods handling within the area where the harbour activities take place (Valdor et al., 2016).	HS <sub>i</sub> /HS <sub>max</sub> [0-1]	
	<b>Harbour Operation (HO)</b>	<b>Dredging probability,</b> frequency of dredging operations.	Continual Periodic None	1.0 0.5 0.0
	<b>Coastal Development (CD)</b>	<b>Land uses</b> developed in a 1-km buffer distance around the harbour (worst case scenario) (Gómez et al., 2019).	Artificial Agricultural Natural - Other uses	1.0 0.5 0.0
<b>State</b>	<b>Susceptibility (SU)</b>	<b>Flushing capacity</b> of the water volume where harbour activities take place, combining hydrodynamic and morphological characteristics through the Complexity Tidal Range Index (CTRI*) (Gómez et al., 2017).	CTRI <sub>i</sub> */CTRI <sub>max</sub> * [0-1]	
	<b>Ecological Value (EV)</b>	Number of <b>Protected areas</b> (#) in a 1-km buffer distance around the surface water area where the harbour activities take place (Gómez et al., 2019).	EV <sub>i</sub> /EV <sub>max</sub> [0-1]	
	<b>Naturalness (NA)</b>	<b>Alteration by hydro-morphological pressures</b> in a harbour's environment (harbour's typology) (US National Geospatial-Intelligence Agency, 2015)	Open Roadstead Natural (Coastal or River) Coastal Breakwater/River Basin Tide Gates (Coastal or River)/Canal or Lake	1.0 0.75 0.5 0.0
<b>Response</b>	<b>Adopted Measures (AM)</b>	Number of <b>adopted measures</b> (#) to reduce the pressure of human activities on the environment (garbage disposal, dirty ballast management, etc.) (Gómez et al., 2019).	AM <sub>i</sub> /AM <sub>max</sub> [0-1]	
	<b>Adopted Instruments (AI)</b>	Number of <b>adopted standards</b> (#) to improve the environmental performance (ISO 14001, EMAS, PERS, others.) (Gómez et al., 2019).	AI <sub>i</sub> /AI <sub>max</sub> [0-1]	

$$*CTRI_i = \left[ 1 - \frac{4 \times A}{\pi \times L^2} \right] \times \frac{e}{R}$$
 Where A is the surface water area where the harbour activities take place (m<sup>2</sup>), L is the diameter of the smallest circle enclosing the surface water area polygon (m), e is the minimum distance between the harbour's infrastructures or the natural elements that conform the harbour's entry (m) and R is the medium tidal range (m) (Gómez et al., 2017).

The range of the potential values of all parameters were normalised (varying from 0 to 1) by dividing the observed value by the maximum value, after discarding outliers for each parameter with values greater than  $\bar{x} \pm 3 \cdot SD$  (Gómez et al., 2019).

### 2.3. Environmental Risk Assessment

To assess the environmental risk to the harbour's aquatic systems, the results of pressure and state factors were classified into four categories (1 to 4), while the response factor was categorised by assigning one of either values: 0 or 4 (Table 2, Eq. 2). Levels separating the different categories were established for all harbours under study using the 25th, 50th and 75th percentile values, with the 50th percentile value used as the threshold between optimal and insufficient response (Table 2).

Table 2. Criteria to assess Pressures ( $Pr_i$ ), State ( $St_i$ ) and Response ( $R_{si}$ ) categories from study site results (VL: Very low; L: low; M: moderate; H: high; P25: 25th Percentile; P50: 50th Percentile; P75: 75th Percentile).

Factor	Category	Criteria	Thresholds
<b>Pressures (Pr)</b>	VL (1)	$Pr_i \leq P_{25}$	$Pr_i \leq 2.11$
	L (2)	$P_{25} < Pr_i \leq P_{50}$	$2.11 < Pr_i \leq 2.51$
	M (3)	$P_{50} < Pr_i \leq P_{75}$	$2.51 < Pr_i \leq 2.58$
	H (4)	$Pr_i > P_{75}$	$Pr_i > 2.58$
<b>State (St)</b>	VL (1)	$St_i \leq P_{25}$	$St_i \leq 0.95$
	L (2)	$P_{25} < St_i \leq P_{50}$	$0.95 < St_i \leq 1.10$
	M (3)	$P_{50} < St_i \leq P_{75}$	$1.10 < St_i \leq 1.37$
	H (4)	$St_i > P_{75}$	$St_i > 1.37$
<b>Response (Rs)</b>	Optimal (0)	$R_{si} \geq P_{50}$	$R_{si} \geq 0.75$
	Insufficient (4)	$R_{si} < P_{50}$	$R_{si} < 0.75$

Obtained scores at the factor level (Table 2) were used to estimate the environmental risk of each harbour through Eq. 1. Based on the environmental risk value (Eq. 1), each harbour

was classified considering three categories: (i) high-risk harbour ( $R_i \geq 12$ ), (ii) moderate-risk harbour ( $6 \leq R_i < 12$ ), (iii) low-risk harbour ( $1 \leq R_i < 6$ ).

### 3. RESULTS

#### 3.1. Identification of harbours

The twenty-seven partners of World Harbour Project network were invited to participate to test the developed ERA method (Steinberg et al., 2016). Fifteen WHP partners were able to encourage harbour managers from their respective cities to participate and to gather the needed information. WHP partners contacted harbour managers by email or phone, and meetings were conducted when necessary. The fifteen harbours, where the developed ERA method was tested, spanned Europe (Dublin, Heraklion, Plymouth, Santander, Ravenna and Vigo), Australasia (Ashdod, Auckland, Darwin, Hobart, Hong Kong, Qingdao and Sydney) and the Americas (Baltimore and Rio de Janeiro) (Figure 1). “Coastal natural harbour” was the typology best represented by seven harbours (Rio de Janeiro, Qingdao, Hong Kong, Santander, Vigo, Darwin and Sydney), followed by “coastal breakwater harbours” represented by four harbours (Ashdod, Dublin, Heraklion, and Ravenna) and “natural river harbours” represented by four harbours (Baltimore, Plymouth, Auckland and Hobart) (Figure 1).

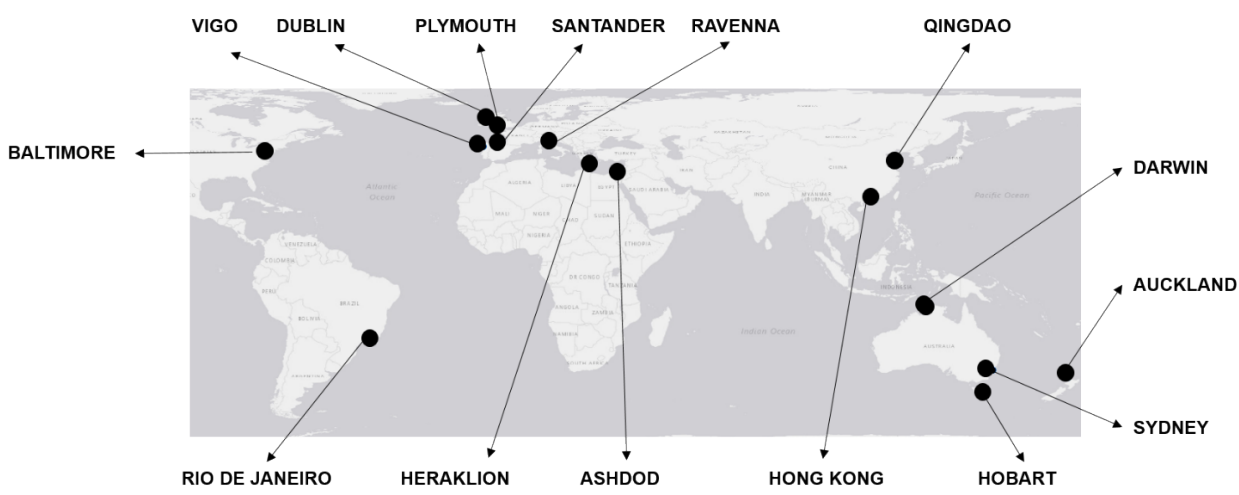


Figure 1. Harbours assessed using the ERA method.

532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590

195 The standardised form (Appendix A) was used to gather information from harbour  
196 managers. Harbour managers sent the filled-in form through email to their respective local  
197 WHP partner. In addition to consulting with harbour managers, where possible, data  
198 collected was cross-checked using global, national (e.g. puertos.es) and local resources or  
199 was specifically sourced from each harbour (e.g. the official web page of each harbour).  
200 Using these sources of information, a database of metrics was generated for each harbour.

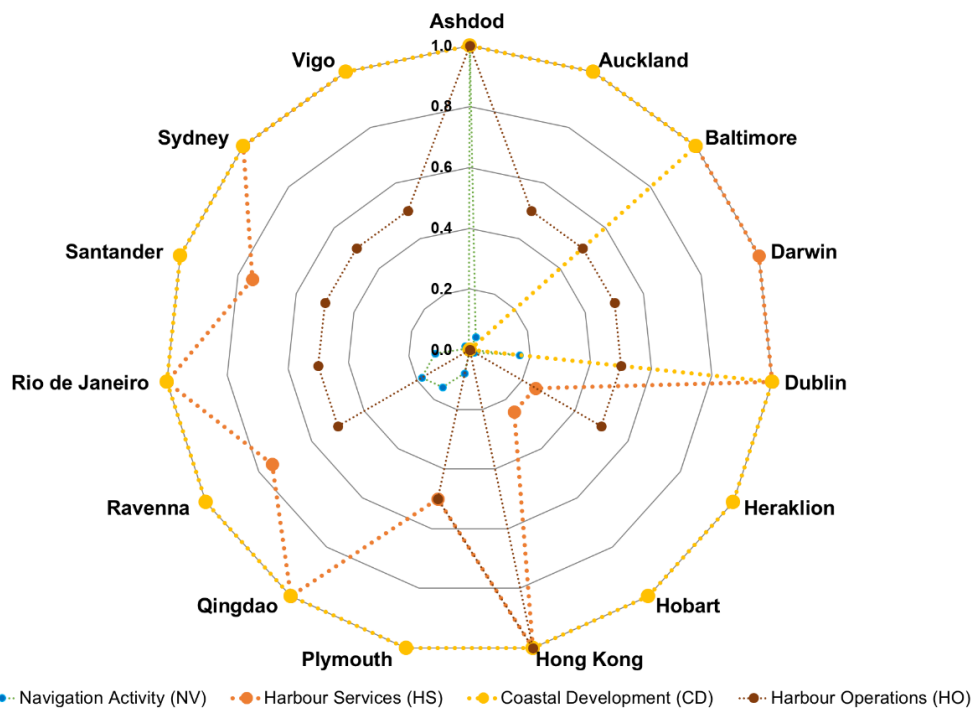
201 **3.2. Estimation of environmental risk**

202 The environmental risk assessment process provided explicit information on the parameters  
203 of risk. To define the spatial scope, a polygon of the surface area of the water where harbour  
204 activities take place was first digitalized using ArcGIS software. Harbour managers were  
205 asked to approve the delimitation of these areas. The resulting polygons indicated harbour  
206 surface-water areas (Supplementary data. Appendix B). The tools “extract by mask” and  
207 “Clip” from the ArcGIS software were used to recognize both land uses and protected areas  
208 in 1-km buffer around each harbour, using Globe Land 30 (Chen et al., 2015) and World  
209 Database on Protected Areas (UNEP-WCMC, 2016), respectively. Mean tidal range (R, m),  
210 as a hydrodynamic characteristic, was calculated from the GOS dataset (Cid et al., 2014);  
211 morphological characteristics were estimated for each harbour using ArcGIS techniques,  
212 including area (A, m<sup>2</sup>), applying the “calculate geometry” tool; length (L, m) and entrance  
213 width (e, m), using the “minimum bounding geometry” tool (Gómez et al., 2017).

214 *Pressures:* Normalised values of navigation activity (NV) were extremely variable among the  
215 studied harbours. Ashdod had the highest density of trade vessels (1), followed by Ravenna  
216 (0.18), Dublin (0.16), Qingdao (0.15) and Rio de Janeiro (0.11), while the other harbours  
217 showed normalised values lower than 0.07 (Figure 2, NV). Most harbour areas showed the  
218 maximum value of Harbour Services (HS), since 10 of the 15 study sites develop fuel oil and  
219 diesel oil supplies, major repair services and dangerous or hazardous goods handling  
220 activities (Figure 2, HS). Exceptions to this were Hobart and Plymouth, where fuel oil supply

591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649

221 and major repairs are not developed, and Heraklion and Ravenna, where dangerous or  
222 hazardous goods handling is not carried out. Harbour Operation (HO) was estimated  
223 through dredging activities, which is are periodic operation in most of the harbours (0.5)  
224 apart from Ashdod and Hong Kong, where continual dredging operations are undertaken  
225 (1), and Hobart and Qingdao, where dredging operations are not carried out (Figure 2, HO).  
226 Normalised Coastal development scored 1 in nearly all the harbours, since the land use  
227 around the harbours was mainly artificial (urban, mining or industrial). Only one harbour  
228 (Darwin) presented natural land uses in its surroundings (Figure 2, CD).

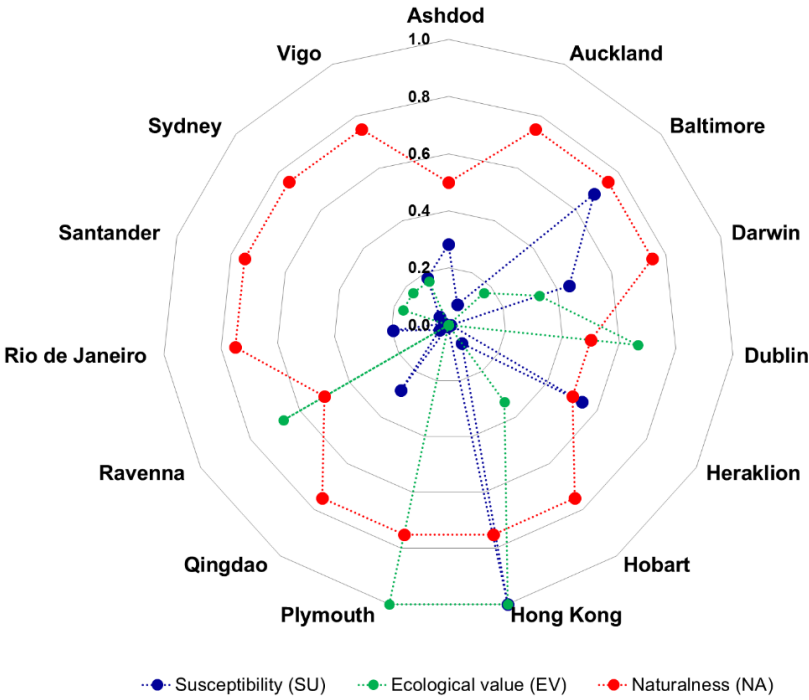


229  
230 Figure 2. Representation of normalised values of the parameters applied for the estimation of the  
231 environmental pressures (Pressures) at each of the 15 studied harbours  
232

233 *State*: Susceptibility (SU, a measure of flushing capacity) was the most variable parameter  
234 of State in all the 15 harbours studied (Figure 3, SU) as it is related to the cleaning capacity  
235 of the water volume, which combines hydrodynamic and morphological characteristics at  
236 the harbour level. The main characteristics of the harbours that were responsible for this  
237 variability were the differences in water surface area (~0.8 km<sup>2</sup> in Plymouth, to 36.73 km<sup>2</sup> in

650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708

238 Darwin), the minimum distance between the elements that conform the harbour's entry (~0.2  
239 km in Ravenna to ~316 km in Darwin) and the variability in tidal ranges (microtidal in the  
240 Mediterranean to a 5 m tidal range in Plymouth). Regarding the Ecological Value (EV), the  
241 number of protected areas located in a 1-km buffer distance around the harbour's water  
242 surface area varied among the different harbours: 0 (five harbours), 1 (four harbours), 2 (two  
243 harbours), 4 (two harbours) and 6 (two harbours) (Figure 3, EV). Conversely, naturalness  
244 (NA) showed similar values at all harbours, with most of them (11) with a normalised NA  
245 value of 0.75 and only 4 harbours with 0.5 (Figure 3, NA).



246  
247 Figure 3. Representation of normalised values of the parameters applied for the estimation of  
248 environmental conditions (State) at each of the 15 studied harbours.  
249  
250 Response: All studied harbours implemented a minimum of 3 Adopted Measures (AM) to  
251 reduce the pressures of human activities on the environment (AM normalised value  $\leq 0.5$ ),  
252 with 8 being the maximum number of measures applied in Qingdao and Baltimore (1 AM  
253 normalised value) (Figure 4, AM). A higher variability was registered in the number of  
254 Adopted Instruments (AI), with eight harbours where no instruments to achieve international

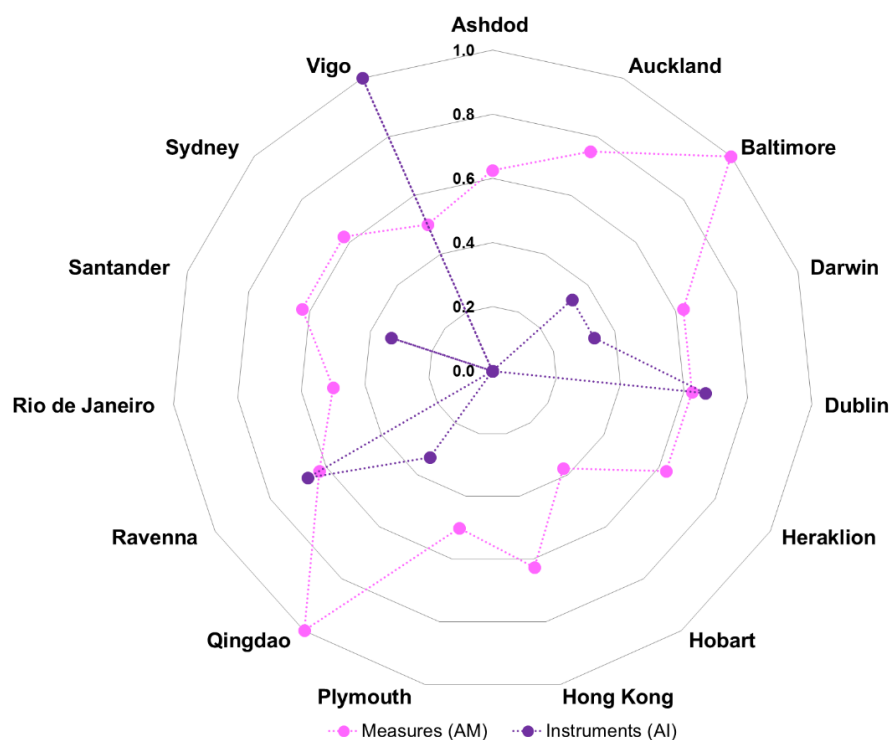


Figure 4. Representation of normalised values of the parameters applied for the estimation of level of response (Response), at each of the 15 studied harbours.

### 3.3. Environmental risk assessment

In terms of Pressure categories, two harbours were assessed to have high environmental pressure with four harbours assessed as being moderate. This was followed by a total of six harbours that were assessed as having low environmental pressures and, finally, three harbours with very low associated pressures (Figure 5, Pressures in blue bars). Regarding the State factor, four harbours were classified within the high category, with three harbours showing moderate environmental conditions and a total of eight harbours within the low and very-low categories (Figure 5, State in yellow bars). Finally, 7 of the 15 studied harbours showed insufficient environmental management, while 8 harbours presented an optimal level of management Response (Figure 5, Response in green bars).



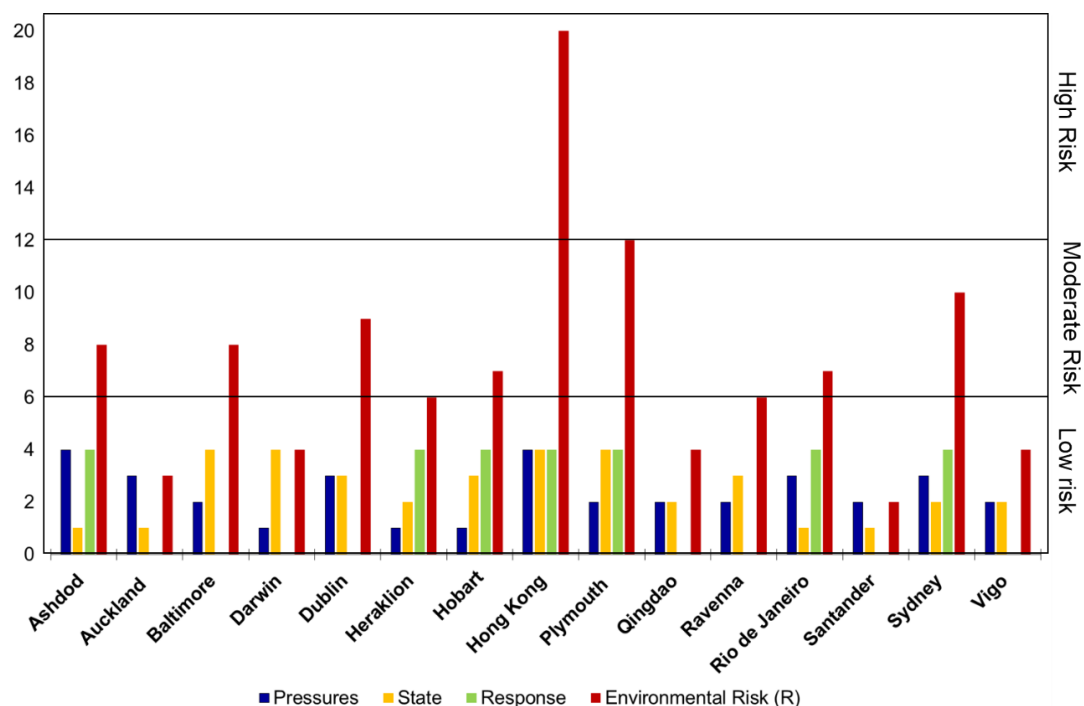


Figure 5. Graphical representation of categorised risk factors (Pressures, State and Response) and categorised environmental risk to aquatic systems at each of the 15 studied harbours.

Results of environmental risk to aquatic systems of harbours, based on this study's results are shown in Supplementary data Appendix B.

## 4. DISCUSSION

### 4.1 Why this ERA method?: The conceptual model

From a conceptual point of view, the Pressure-State-Response (PSR) model (OECD, 2003) is used as a framework to select indicators that assess environmental risk at the harbour level, based on Gómez et al., (2019). Moreover, the Driving force-Pressure-State-Impact-Response (DPSIR) model (EEA, 2005) is integrated in the PSR model to define specific indices of Pressure, State and Response. These indices group and classify a small number of indicators (Figure 6).

827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885

289 From a practical point of view, the selection of general-purpose indicators for global  
290 assessments was complex because of the need to obtain homogeneous, objective and  
291 systematic, open and publicly available data and information on a series of diverse  
292 parameters from analogous entities (harbours) that are under different socio-ecological  
293 contexts from all over the world. Indicators were selected based on: i) the complementarity  
294 and non-redundancy of indicators in their representation of risk factors; ii) the possibility of  
295 finding available and homogeneous data from harbours worldwide, and iii) state-of-the-art  
296 and previous studies.

297

298 Driving forces describe the social, demographic and economic development within a given  
299 harbour (EEA, 2005). Based on the conceptual model presented (Figure 6), indicators  
300 selected to estimate the environmental pressures include the four main driving forces  
301 relevant to the harbour areas (navigation, harbour services, harbour operation and coastal  
302 development). Navigation activity, estimated as the number of trade vessel visits per year  
303 by a water-surface area of a harbour, was selected, as it has been identified in previous  
304 works as a representative environmental stressor (Antão et al., 2016) and it is easily  
305 accessible from institutional statistics (e.g. Eurostat, or individual webpages of harbours).  
306 Regarding Harbours Services (HS), two indicators were selected: i) major repair services  
307 (shipyards, ship repair or painting, etc.) that generate chemical wastes (heavy metals, PAHs  
308 and antifoulants), which can pose a risk to aquatic organisms inhabiting harbour areas  
309 (Bebianno et al., 2015); and ii) dangerous/hazardous goods handling defined by IMO codes  
310 (IMO, 2014), which were previously considered in ERA mapping studies on harbour systems  
311 (e.g. Valdor et al., 2016). Furthermore, dredging, one of the most important operations and  
312 maintenance activities within harbours (PIANC, 2006), and dominant land use in the  
313 surrounding area, served as proxies of the external influences on water quality (Cornelissen  
314 et al., 2008).

315

886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944

316 Indirect or direct pressures are identified by each driving force (Gómez et al., 2019). The  
317 identified pressures produce impacts altering the state of the environment (Ondiviela et al.,  
318 2013; Petrosillo et al., 2010). State factor of risk considers three important aspects of the  
319 harbour's environment: susceptibility, ecological value and naturalness. From the eight  
320 pressure indicators proposed in the conceptual model (Figure 6), there are three related to  
321 quality of the aquatic system (chemical quality, physico-chemical quality and biological  
322 quality) that require periodic monitoring and systematic evaluation. Since each country  
323 applies different monitoring and evaluation systems (in terms of thresholds, frequency, etc.),  
324 the susceptibility to water and sediment contamination was considered as a standard  
325 representative indicator of the quality of the aquatic system of harbours worldwide, assuming  
326 a significant relationship between flushing capacity and water quality in littoral areas  
327 (Ferreira et al., 2005; Fortes and Silva., 2006; Gómez et al, 2014; Yin et al., 2000). This  
328 assumption was previously used for ERA in marinas (Gómez et al., 2017) and harbours  
329 (Gómez et al., 2015). The harbour's ecological value considered that the greater the  
330 protected area in the vicinity of the harbours is, the greater the biodiversity and ecological  
331 processes that maintain that system (Gómez et al., 2015; Langanke et al., 2005; Margulles  
332 and Usger, 1981). Finally, their 'naturalness' (Machado, 2004) was estimated using the  
333 harbour typology (US National Geospatial-Intelligence Agency, 2015) as a surrogate of  
334 number and dimensions of hydro-morphological pressures at the marina level typology  
335 (Gamito, 2008; Gómez et al., 2019).

336

337 The response factor to environmental risk was used to integrate the actions and reactions,  
338 intended to mitigate, adapt to or prevent human-induced negative effects on the environment  
339 that could be applied to minimize the impacts of driving forces and improve the state of  
340 aquatic ecosystems (OECD, 2003). Responses may arise from different sectors, such as  
341 those in social, technical or institutional (i.e. local, national or international administrations)  
342 realms (Figure 6). Among all of them, institutional responses are the option that integrates  
343 a greater number of fields involving social responses (awareness campaigns), institutional

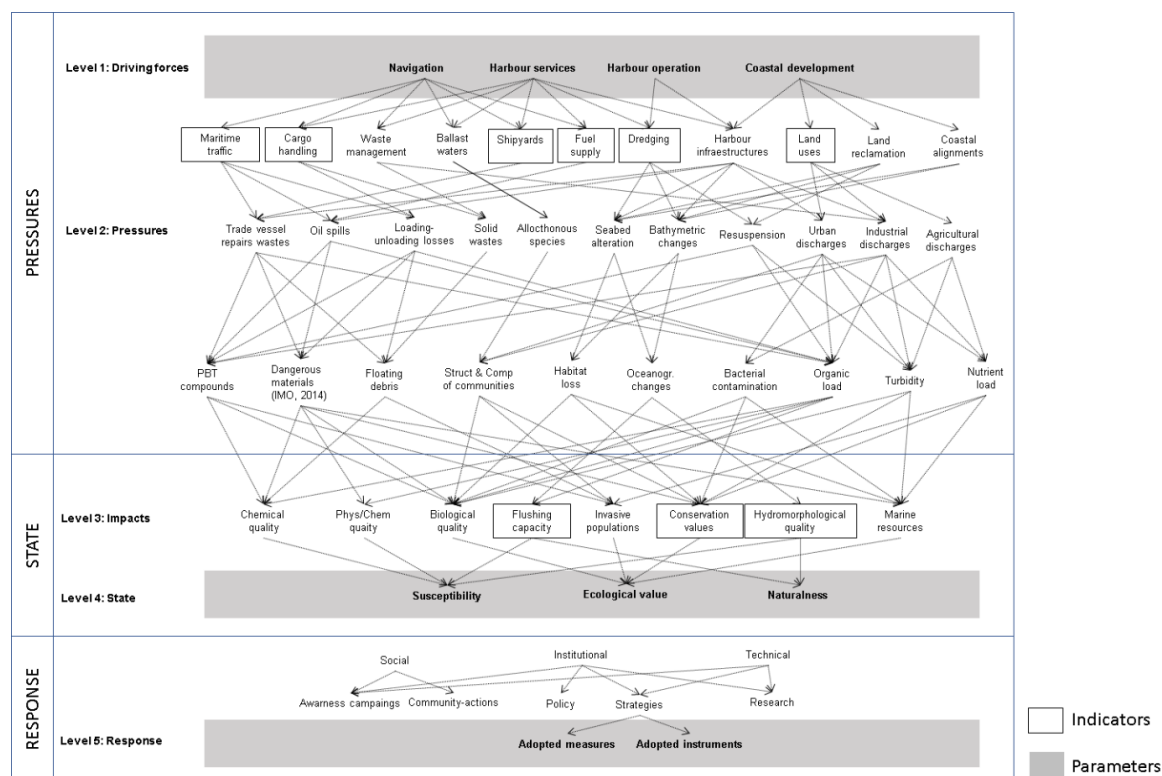


Figure 6. Conceptualisation of the causal links between main driving forces, pressures, impacts, state and response of aquatic systems in harbours.

## 4.2 The global implementation

Based on this study's results, the method used provides a tool to standardize the assessment of environmental risk to aquatic systems at a global scale (Supplementary data Appendix B). However, a question arose from this implementation: Are the PSR and DPSIR scenarios of the study sites representative of the environmental risks of harbours globally? ERA results showed that most of the study areas had a moderate risk but included significant variability of environmental pressures, environmental conditions and societal responses. However, results showed differences at the indicator level in those harbours within the same

1004  
1005  
1006  
1007  
1008  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1060  
1061  
1062

361 category of risk. For instance, Hobart showed a moderate environmental risk on the aquatic  
362 system due to a combination of high vulnerability (high naturalness but a moderate  
363 ecological value of the surroundings) with a high score of environmental management (due  
364 to the low number of adopted measures and none of the international standards  
365 implemented). Heraklion showed a moderate risk on the aquatic system even though they  
366 were adopting a good number of environmental measures (above the average) to reduce  
367 the pressure of human activities on the environment because no international environmental  
368 management instruments were applied. In other cases, the higher susceptibility (Baltimore)  
369 or the higher ecological value (Ravenna), were the parameters of risk that penalised the  
370 result for these harbours. Identification of such risk parameters allows for the targeted  
371 application of more preventive and corrective management actions to help reduce  
372 environmental risk to aquatic systems for those specific harbours.  
373 Therefore, from a practical perspective, the environmental risk assessment method can be  
374 used as a tool to proactively identify the most important factors of risk on which to apply  
375 actions that allow for environmental improvements in each.  
376 For this, expert knowledge on environmental risk is not strictly necessary, but a deep  
377 understanding on the environment harbour characteristics is needed. These data are  
378 controlled and known by harbour managers. In Section 2, practical steps are described  
379 considering parameters, indicators, metrics and criteria to estimate each risk factor. The  
380 pathway to apply the ERA method to an individual harbour include the collection of the  
381 information needed and the calculation of parameters for each risk factor. A standardized  
382 form to gather the information is provided in Appendix A and calculations described at  
383 Section 2 are easy to apply with a basic knowledge of spatial analysis using geographical  
384 information systems.  
385 Once applied, the method can be used to detect which harbours should apply environmental  
386 measures or/and international standards to improve their management of aquatic systems,  
387 based on the highest standards of environmental quality applied around the world. An  
388 example of this is shown in Figure 7, which represents the hypothetical case in which the 15

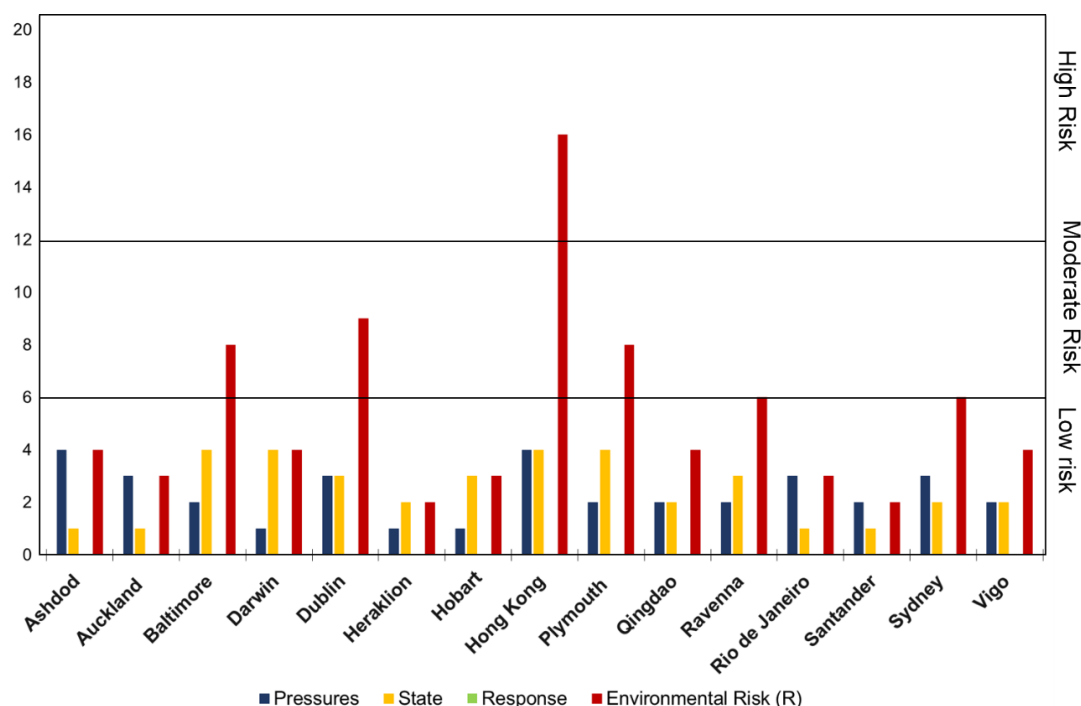


Figure 7. Graphical representation of a hypothetical situation at each of the 15 studied harbours with reduced categorised risk factors (pressures, state and responses) by the application of at least 4 environmental measures and 1 international standard and categorised environmental risk to aquatic systems.

In this case, one harbour continues to show high risk, five harbours show moderate risk while the other nine show a low environmental risk on the aquatic system. The screening capacity of this tool may address the global challenge of standardizing methods that produce comparable risk assessments of high-level entities (e.g. harbours) at large spatial scales. However, if the harbours applying the environmental measures and certifications do not obtain a low value of environmental risk, they should then focus their efforts on reducing the

1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1180

406 environmental risk factors that are penalizing the final value of environmental risk. This is  
407 the case in Hong Kong, which has high pressures due to the presence of intense navigation  
408 activity (NV), the harbour services (HS) provided in the harbour, the continual dredging  
409 activity (DG) in the harbour area and the Coastal development (CD) in their surroundings.  
410 Baltimore is also highly susceptible probably due to the morphological characteristics of the  
411 harbour area, which is very difficult to change from an environmental management  
412 standpoint. In these cases, socio-economic issues should also be incorporated into a long-  
413 term sustainability or management plan, which must assess the disadvantages and benefits  
414 that may result from modifying factors that penalized the final value of the environmental  
415 risk.

416

417 To the extent that harbours collaborate by providing the necessary information for the  
418 calculation of environmental risk, it will be possible to create a global atlas of risk.  
419 Collaboration by harbours will be feasible as long as the global atlas were understood as a  
420 participatory process towards the sustainability of aquatic systems, recalling the adoption of  
421 the 2030 Agenda and its Sustainable Development Goals (SDG, in particular SDG 14) and  
422 the more recent resolution of the UN on the Decade for Ocean Sciences (2021-30), which  
423 will provide a unifying framework across the UN system to enable countries to achieve all of  
424 their ocean-related Agenda 2030 priorities (IOC, 2017).

425

426 The global atlas developed by using the method presented herein would introduce valuable  
427 ~~bring the~~ elements of judgment to guide managers involved in decision-making (AENOR,  
428 2008) towards the sustainability of aquatic systems in harbour areas, as well as to design  
429 the first global strategy for sustainability related to the water quality at a global level.  
430 Sustainable development goal (SDG) 14 in the UN 2030 Agenda requires to “conserve and  
431 sustainably use the oceans, seas and marine resources for sustainable development”  
432 (United Nations, 2015). Global Sustainable development goals require global analysis of the  
433 problems presented and definition of global strategies to resolve them. Many critical

1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239

434 management and conservation challenges of aquatic systems in harbour areas are  
435 inherently spatial issues (Valdor et al., 2016). As new spatial data are collected on the  
436 distribution and intensity of harbour activities, this will allow for more flexible and adaptive  
437 environmental management processes to identify global environmental problems and  
438 possible sustainable solutions through an environmental risk assessment approach.

439

440 Future work could improve the current Atlas through the collection and comparison of more  
441 data from more harbours across the globe, and it also could test for the robustness of this  
442 approach. In addition, new indicators could be developed to improve the method proposed.  
443 For example, the navigation and docking of cruise ships or fishing vessels could serve as a  
444 complementary indicator for the parameter of risk related to navigation activity (NV), and an  
445 international connectivity index of harbours could be an indicator of the potential  
446 environmental risks from invasive species.

## 447 **5. CONCLUSIONS**

448 In this study, we present the first example of an Environmental Risk Assessment (ERA)  
449 screening approach to assess the environmental risk on aquatic systems in harbours at  
450 global scale. The method implemented in this attempt proposes a semi-quantitative and  
451 simple-method to assess the environmental risk on aquatic systems in harbour areas  
452 worldwide. The implementation of the method to the 15 diverse harbours has provided  
453 sound evidence for the usefulness, versatility and adaptability of the proposed ERA method  
454 as a management tool. The method is flexible enough to be applied to any harbour  
455 worldwide using international open-databases. The implementation of this method to a wider  
456 number of study cases would allow identification of harbours that could improve their  
457 environmental management through the implementation of measures with specific  
458 indicators. The method lays the foundation of a global atlas for the sustainability of  
459 commercial harbours and it provides a powerful tool to facilitate the design of a strategy for  
460 the sustainability of the harbour sector at a global level.



1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298

## 461   **Acknowledgments**

462   In Memoriam of Professor José Antonio Revilla Cortezón (Pepe), former leader of the  
463   Environmental Management Group of the University of Cantabria.

464   This work was supported by the World Harbour Project ([www.worldharbourproject.org](http://www.worldharbourproject.org)) and  
465   its supporters, including The Ian Potter Foundation, the NSW State Government and the  
466   SIMS Foundation. Authors would like to thank all the harbour managers worldwide who  
467   provided their time to complete the forms to gather relevant information for this study.

## 468   **Supplementary data**

### 469   **Appendix A.**

470   The appendix includes the standard form aimed to collected data from each harbour.

### 471   **Appendix B.**

472   These data include the Google map (.kml) of the Atlas of environmental risk to aquatic  
473   systems in the 15 harbours analysed.

## 474   **REFERENCES**

- 475   AENOR, 2008. UNE 150008:2008. Análisis y evaluación del riesgo ambiental.  
476   AENOR. Madrid. 46 pp.
- 477   Antão, P., Calderón, M., Puig, M., Michail, A., Wooldridge, C., Darbra, R.M., 2016.  
478   Identification of occupational health, safety, security (OHSS) and  
479   environmental performance indicators in port areas. Saf. Sci. 85, 266–275.  
480   doi:10.1016/j.ssci.2015.12.031
- 481   Bebianno, M.J., Pereira, C.G., Rey, F., Cravo, A., Duarte, D., D'Errico, G., Regoli,  
482   F., 2015. Integrated approach to assess ecosystem health in harbor areas.  
483   Sci. Total Environ. 514, 92–107. doi:10.1016/j.scitotenv.2015.01.050
- 484   Brolsma, J.U. 2010. PIANC, The World Association for Waterborne Transport  
485   Infrastructure, an association in a changing world, 1885-2010. Brussels,  
486   Belgium. Peeters N.V. 175pp.
- 487   Chen J., Chen J., Liao A., Cao X., Chen L., Chen X., He C., Han G., Peng S., Lu  
488   M., Zhang W., Tong X., Mills J., 2015 Global land cover mapping at 30m  
489   resolution: A POK-based operational approach. ISPRS J. Photogr. Rem.  
490   Sens.103, 7-27. doi:10.1016/j.isprsjprs.2014.09.002

1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357

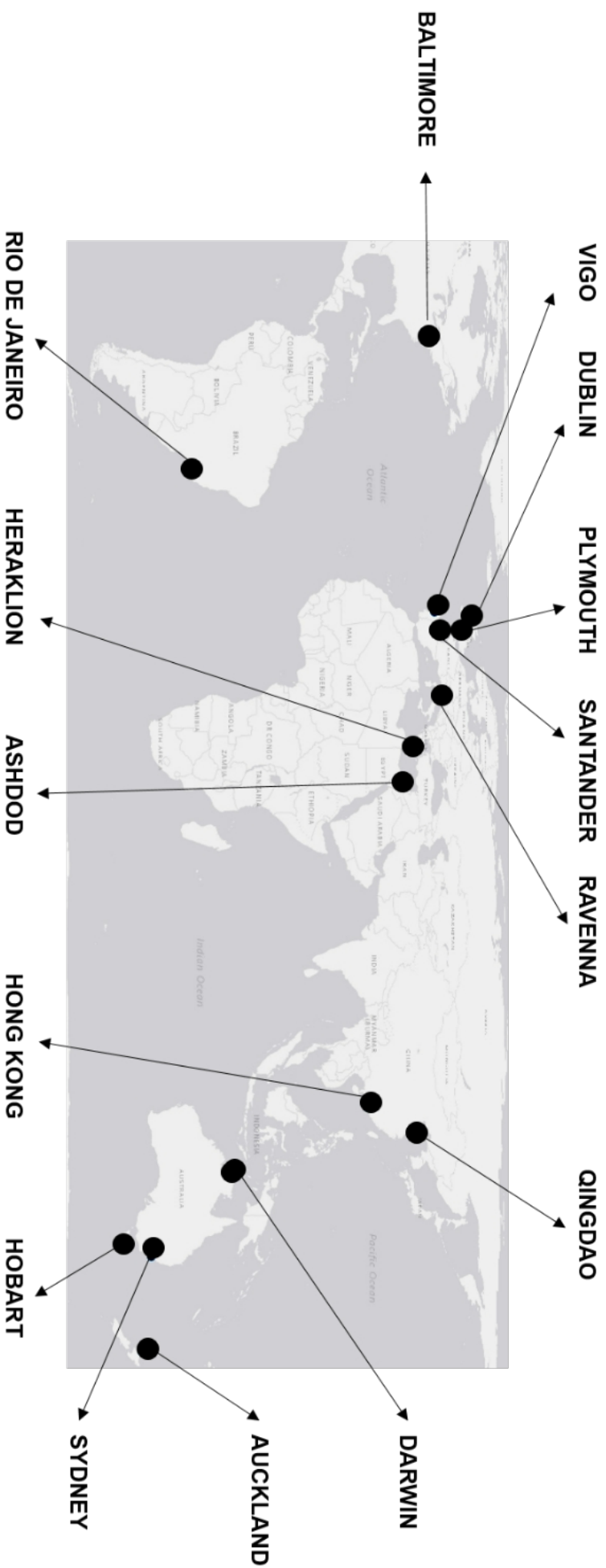
- 491 Cid A., Castanedo S., Abascal A.J., Menéndez M., Medina R., 2014. A high  
492 resolution hindcast of the meteorological sea level component for Southern  
493 Europe: the GOS dataset. *Clim Dyn.* 43, 7-8, 2167-2184. doi: 10.1007/s00382-  
494 013-2041-0
- 495 Cornelissen, G., Pettersen, A., Nesse, E., Eek, E., Helland A., Breedveld, G.D.,  
496 2008. The contribution of urban runoff to organic contaminant levels in harbour  
497 sediments near two Norwegian cities. *Mar. Pollut. Bull.* 56, 565–573.  
498 doi:10.1016/j.marpolbul.2007.12.009
- 499 Darbra, R.M., Ronza, A., Stojanovic, T.A., Wooldridge, C., Casal, J., 2005. A  
500 procedure for identifying significant environmental aspects in sea ports. *Mar.*  
501 *Pollut. Bull.* 50. doi:10.1016/j.marpolbul.2005.04.037
- 502 EC, 2013. Ports 2030, Gateways for the TransEuropean Transport Network.  
503 European Commission. 26 pp.
- 504 EEA, 2005. EEA core set of indicators — guide. In: EEA Technical Report No  
505 1/2005. 1725-2237. Luxembourg. 38 pp.
- 506 ESPO-ECOPORTS, 2019. European Port Industry Sustainability Report 2019. 23  
507 pp.
- 508 Ferreira, J.G., Wolff, W.J., Simas, T.C., Bricker, S.B., 2005. Does biodiversity of  
509 estuarine phytoplankton depend on hydrology? *Ecol. Model.* 187 (4), 513e523.  
510 doi: 10.1016/j.ecolmodel.2005.03.013.
- 511 Fortes, J., Silva, C., 2006. Temporal and spatial distribution of dissolved oxygen in  
512 the Ria de Aveiro lagoon. *Ecol. Model.* 197 (1e2), 67e88. doi:  
513 10.1016/j.ecolmodel.2006.03.012.
- 514 Gamito, S., 2008. Three main stressors acting on the Ria Formosa lagoonal  
515 system (Southern Portugal): physical stress, organic matter pollution and the  
516 land ocean gradient. *Estuar. Coast. Shelf Sci.* 77, 710e720.  
517 doi:10.1016/j.ecss.2007.11.013.
- 518 Gómez, A.G., Juanes, J.A., Ondiviela, B., Revilla, J.A., 2014. Assessment of  
519 susceptibility to pollution in littoral waters using the concept of recovery time.  
520 *Mar. Pollut. Bull.* 81 (1), 140–148. doi: 10.1016/j.marpolbul.2014.02.004.
- 521 Gómez, A. G., Ondiviela, B., Puente, A., Juanes, J. A., 2015. Environmental risk  
522 assessment of water quality in harbor areas: A new methodology applied to  
523 European ports. *J. Environ. Manage.* 155, 77–88. doi:  
524 10.1016/j.jenvman.2015.01.042
- 525 Gómez, A G., Ondiviela, B., Fernández, M., Juanes, J.A., 2017. Atlas of  
526 susceptibility to pollution in marinas. Application to the Spanish coast. *Mar.*  
527 *Pollut. Bull.* 114, 239-346. doi:10.1016/j.marpolbul.2016.09.009

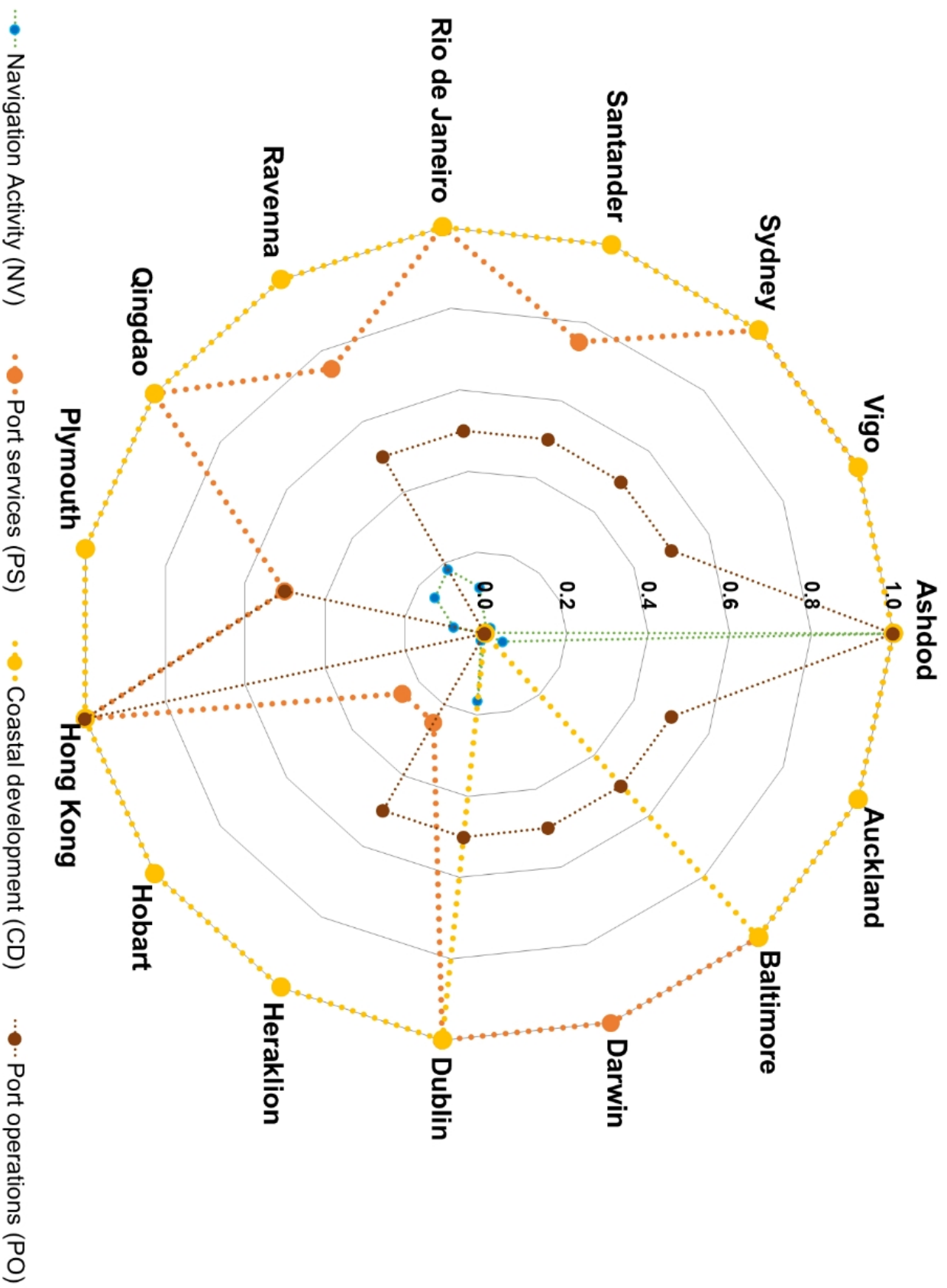
1358  
1359  
1360 528 Gómez, A G., Valdor, P.F., Ondiviela, B., Díaz, J.L., Juanes, J.A., 2019. Mapping  
1361 529 the environmental risk assessment of marinas on water quality: The Atlas of  
1362 530 the Spanish coast. *Mar. Pollut. Bull.* 139, 355-365.  
1363 531 doi:10.1016/j.marpolbul.2019.01.008  
1364  
1365 532 Grifoll, M., Jordá, G., Borja, A., Espino, M., 2010. A new risk assessment method  
1366 533 for water quality degradation in harbour domains, using hydrodynamic models.  
1367 534 *Mar. Pollut. Bull.* 60, 69–78. doi:10.1016/j.marpolbul.2009.08.030  
1368  
1369  
1370 535 Gupta A.K., Gupta S.K., Patil R.S., 2005. Environmental management plan for port  
1371 536 and harbour projects. *Clean Techn Environ Policy*. 7 (2), 133-141.  
1372 537 doi:10.1007/s10098-004-0266-7  
1373  
1374 538 Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C.,  
1375 539 Bruno, J.F., Kenneth S. C., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., S.  
1376 540 Lenihan, Elizabeth M. P. Madin, Matthew T. Perry, Elizabeth R. Selig, Mark  
1377 541 Spalding, H., Steneck, R., Watson, R. , 2008. A Global Map of Human Impact  
1378 542 on Marine Ecosystems. *Science*, 319 (5865), 948–952.  
1379 543 doi:10.1126/science.1149345  
1380  
1381 544 Hope, B.K., 2006. An examination of ecological risk assessment and management  
1382 545 practices. *Environ. Int.* 32, 983–995. doi:10.1016/j.envint.2006.06.005  
1383  
1384 546 ICS, 2018. International chamber of shipping. Annual Review 2018. London. 64 pp.  
1385  
1386 547 ICS, 2019. International chamber of shipping. Annual Review 2019. London. 72 pp.  
1387  
1388 548 IMO, 2004. International Convention for the Control and Management of Ships'  
1389 549 Ballast Water and Sediments (BWM). International Maritime Organization.  
1390 550 IMO Publisher, London. 7 pp.  
1391  
1392 551 IMO, 2013. IMSBC Code. International maritime solid bulk cargoes code and  
1393 552 supplement, 2013 ed. International Maritime Organization. IMO Publisher,  
1394 553 London. 558 pp.  
1395  
1396 554 IMO, 2014. IMDG Code. International maritime dangerous goods code. 2014 ed.  
1397 555 International Maritime Organization. IMO Publisher, London. 22 pp.  
1398  
1399  
1400 556 Intergovernmental Oceanographic Commission of UNESCO, 2017. Information  
1401 557 document: International (UN) Decade of Ocean Science for Sustainable  
1402 558 Development. "Towards the ocean we need for the future we want". Paris. 23  
1403 559 pp.  
1404  
1405 560 Juanes, J. A., Ondiviela, B., Gómez, A. G., Revilla, J.A., 2013. Recommendation  
1406 561 for Maritime Works. ROM 5.1-13. Quality of coastal waters in port areas of the  
1407 562 Spanish National Port Administrations. Ministry of Public Works, Madrid. 141  
1408 563 pp.  
1409  
1410 564 Juanes, J.A., Gómez, A.G., Rubio, S., García-Castrillo, G., Puente, A., Ondiviela, B.,  
1411 565 Medina, R. 2020. Santander Bay: Multiuse and multiuser socioecological  
1412  
1413  
1414  
1415  
1416

1417  
1418  
1419 566 space. *Regional Studies in Marine Science*, 34-101034.  
1420 567 DOI: 10.1016/j.rsma.2019.101034  
1421  
1422 568 Knights, A.M., Piet, G.J., Jongbloed, R., Tamis, J.E., Robinson, L.A., et al., 2015.  
1423 569 An exposure-effect approach for evaluating ecosystem-wide risks from human  
1424 570 activities. *ICES J. Mar. Sci.* 72, 1105–1115. doi:10.1093/icesjms/ fsu245.  
1425  
1426 571 Langanke, T., Rossner, G., Vrscaj, B., Lang, S., Mitchley, J., 2005. Selection  
1427 572 and application of spatial indicators for nature conservation at different  
1428 573 institutional levels. *J. Nat. Conserv.* 13, 101e114.  
1429 574 doi:10.1016/j.jnc.2005.01.005  
1430  
1431  
1432 575 Lethbridge, J.R. 1991. MARPOL 73/78 (International Convention for the Prevention  
1433 576 of Pollution from Ships) (English). Infrastructure notes ; no. PS-4. Washington  
1434 577 DC : World Bank.  
1435 578 [http://documents.worldbank.org/curated/en/860841468330898141/MARPOL-](http://documents.worldbank.org/curated/en/860841468330898141/MARPOL-73-78-International-Convention-for-the-Prevention-of-Pollution-from-Ships)  
1436 579 [73-78-International-Convention-for-the-Prevention-of-Pollution-from-Ships](http://documents.worldbank.org/curated/en/860841468330898141/MARPOL-73-78-International-Convention-for-the-Prevention-of-Pollution-from-Ships)  
1437  
1438 580 Machado, A., 2004. An index of naturalness. *J. Nat. Conserv.* 12, 95e110.  
1439 581 doi:10.1016/j.jnc.2003.12.002.  
1440  
1441 582 Margules, C., Usger, M.B., 1981. Criteria used in assessing wildlife conservation  
1442 583 potential: a review. *Biol. Conserv.* 21, 79e109. doi: 10.1016/0006-  
1443 584 3207(81)90073-2.  
1444  
1445 585 OECD, 2003. Environmental Indicators. Development, Measurement and Use. The  
1446 586 Organisation for Economic Co-operation and Development, Paris, 37pp.  
1447  
1448 587 Ondiviela, B., Juanes, J.A., Gómez, A.G., Samano, M.L., Revilla, J.A., 2012.  
1449 588 Methodological procedure for water quality management in port areas at the  
1450 589 EU level. *Ecol. Indic.* 13, 117–128. doi: 10.1016/ j.envsci.2013.07.001.  
1451  
1452 590 Parra, N.M., Nagi, A., Kersten, W., 2018. Risk Assessment Methods in Seaports: A  
1453 591 Literature Review. Publications of the Hazard Project 24:2018.69 pp.  
1454  
1455 592 Petrosillo, I., Vassallo, P., Valente, D., Mensa, J.A., Fabiano, M., Zurlini, G., 2010.  
1456 593 Mapping the environmental risk of a tourist harbor in order to foster  
1457 594 environmental security: objective vs. subjective assessments. *Mar. Pollut. Bull.*  
1458 595 60, 1051–1058. <https://doi.org/10.1016/j.marpolbul.2010.01.021>.  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1470  
1471  
1472  
1473  
1474  
1475

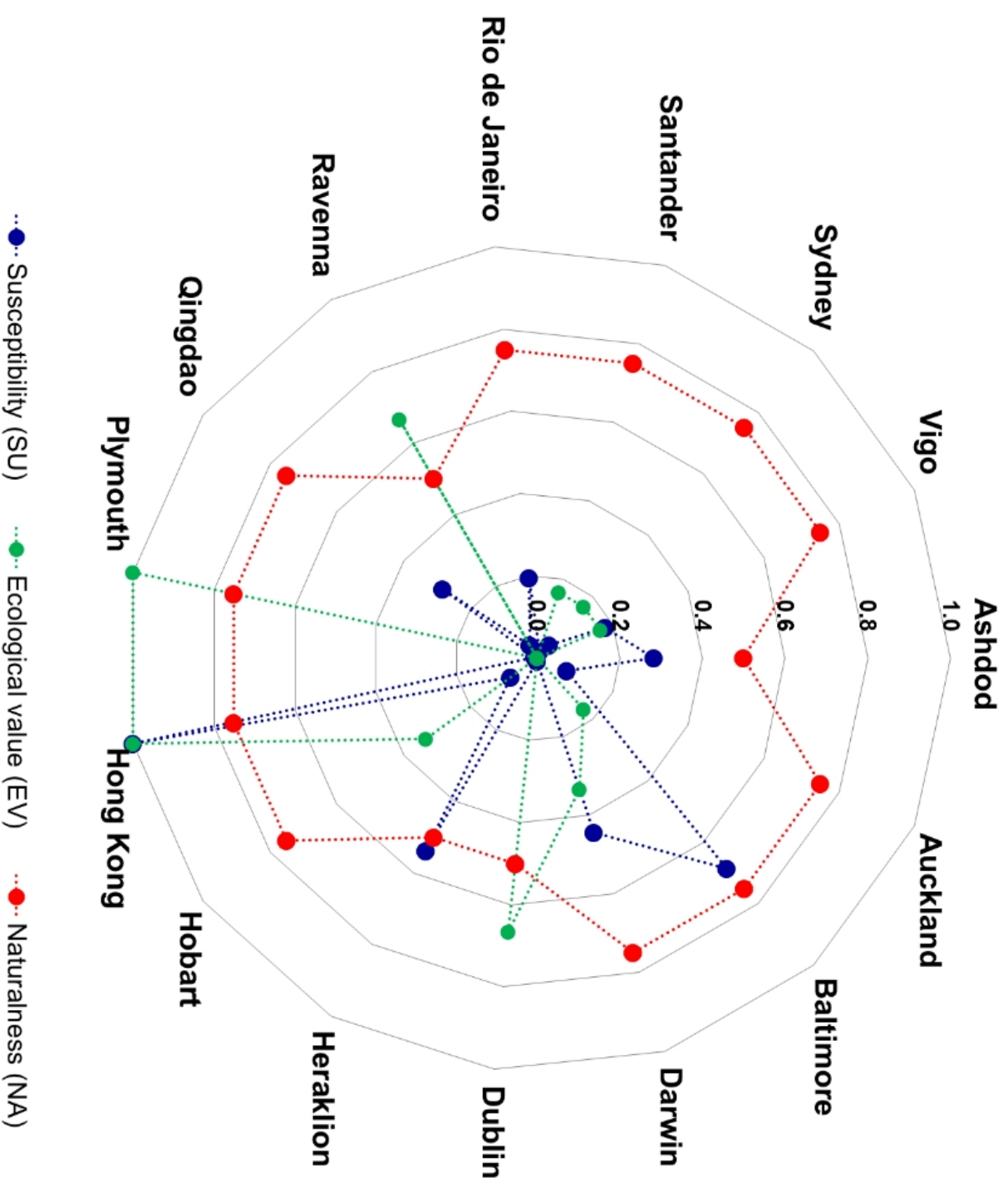
1476  
1477  
1478 596 PIANC, 2011. Towards a Sustainable Waterborne Transportation Industry.  
1479 597 EnviCom Task Group 2. September 08, 2011.  
1480  
1481  
1482  
1483 598 PIANC, 2019. A Practical Guide to Environmental Risk Management (ERM) for  
1484 599 Navigation Infrastructure Projects. EnviCom WG 175. October 24, 2019.  
1485  
1486  
1487  
1488 600 PIANC, 2020. Climate Change Adaptation Planning for Ports and Inland  
1489 601 Waterways. EnviCom WG 178. January 09, 2020.  
1490  
1491  
1492 602 PIANC, 2006. Environmental Risk Assessment of Dredging and Disposal  
1493 603 Operations. PIANC Secretariat General, Brussels.40 pp.  
1494  
1495 604 Puig, M., Wooldridge, C., Casal, J., Darbra, R.M., 2015. Tool for the identification  
1496 605 and assessment of Environmental Aspects in Ports (TEAP). Ocean Coast.  
1497 606 Manag. 113, 8–17. doi:10.1016/j.ocecoaman.2015.05.007  
1498  
1499 607 Ronza, A., Carol, S., Espejo, V., Vílchez, J.A., Arnaldos, J., 2006. A quantitative  
1500 608 risk analysis approach to port hydrocarbon logistics. J. Hazard. Mater. 128 (1),  
1501 609 10e24. doi:10.1016/j.jhazmat.2005.07.032.  
1502  
1503 610 Samhouri, J., & Levin, P.S., 2012. Linking land- and sea-based activities to risk in  
1504 611 coastal ecosystems. Biol. Conserv. 145, 118–129. doi:  
1505 612 10.1016/j.biocon.2011.10.021  
1506  
1507 613 Smith, A.D.M., Fulton, E.J., Hobday, A.J., Smith, D.C., Shoulder, P., 2007.  
1508 614 Scientific tools to support the practical implementation of ecosystem-based  
1509 615 fisheries management. ICES J. Mar. Sci. 64, 633–639.  
1510 616 doi:10.1093/icesjms/fsm041  
1511  
1512 617 Steinberg, P.D., Airoldi, L., Banks, J., Leung, K.M.Y., 2016. Introduction to the  
1513 618 special issue on the World Harbour Project. Reg. Stud. Mar. Sci., 8 (2), 217-  
1514 619 219. doi:10.1016/j.rsma.2016.10.001  
1515  
1516 620 Strain E, Alexander K, Kienker S, Morris R, Jarvis R, Coleman R, Bollard B, Firth L,  
1517 621 Knights A, Grabowski J. 2019.Urban blue: a global analysis of the factors  
1518 622 shaping people's perceptions of the marine environment and ecological  
1519 623 engineering in harbours. SciTotal Environ 658:1293–1305.  
1520 624 https://doi.org/10.1016/j.scitotenv.2018.12.285  
1521  
1522  
1523 625 UNCTAD, 2012. Review of Maritime Transport 2012. United Nations. New York  
1524 626 and Geneva. United Nations.196 pp.  
1525  
1526 627 UNCTAD, 2017. Review of maritime transport 2017. United Nations Conference on  
1527 628 Trade and Development Review. New York and Geneva.130 pp.  
1528  
1529  
1530  
1531  
1532  
1533  
1534

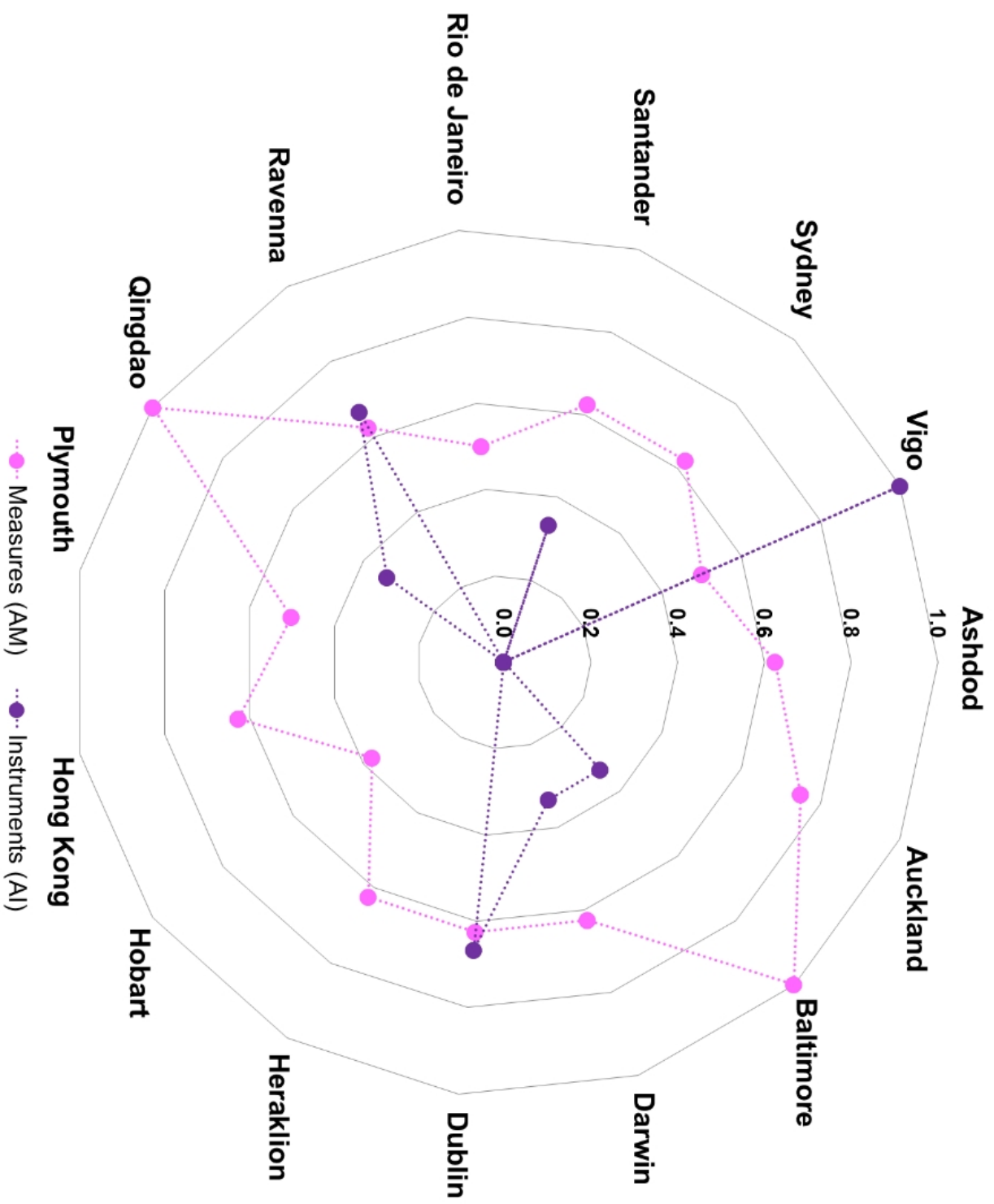
1535  
1536  
1537 629 UNEP-WCMC, 2016. World Database on Protected Areas. United Nations  
1538 630 Environment World Conservation Monitoring Centre - World Commission on  
1539 631 Protected Areas (<https://www.protectedplanet.net/>).  
1540  
1541 632 United Nations, 2015. Transforming our world: the 2030 Agenda for Sustainable  
1542 633 Development. General Assembly 70 Session, 16301 (October), 1–35.  
1543 634 doi:10.1007/s13398-014-0173-7.2  
1544  
1545 635 US National Geospatial-Intelligence Agency, 2015. World Port Index, Pub 150. 250  
1546 636 pp.  
1547  
1548 637 Valdor, P.F., Gómez, A.G., Ondiviela, B., Puente, A., Juanes, J.A., 2016.  
1549 638 Prioritization maps: the integration of environmental risks to manage water  
1550 639 quality in harbor areas. Mar. Pollut. Bull., 111 (1–2) 57-67. doi:  
1551 640 10.1016/j.marpolbul.2016.07.028  
1552  
1553 641 Valdor, P.F., Puente, A., Gómez, A.G., Ondiviela, B., Juanes, J.A., 2017. Are  
1554 642 environmental risk estimations linked to the actual environmental impact?  
1555 643 Application to an oil handling facility (NE Spain). Mar. Pollut. Bull. 114, 941–  
1556 644 951. doi:10.1016/j.marpolbul.2016.10.078  
1557  
1558 645 Valdor, P.F., Gómez, A.G., Juanes, J.A., Kerléguer, C., Steinberg, P., Tanner, E.,  
1559 646 MacLeod, C., Knights, A.M., Seitz, R.D., Airoldi, L., Firth, L.B., Crowe, T.,  
1560 647 Chatzinikolaou, E., Smith, A., Arvanitidis, C., Burt, J.A., Brooks, P.R., Ponti,  
1561 648 M., Soares-Gomes, A., Ovejero, A., Méndez, G., 2019. A global atlas of the  
1562 649 environmental risk of marinas on water quality. Mar. Pollut. Bull. 149, 110661.  
1563 650 doi:10.1016/j.marpolbul.2019.110661  
1564  
1565 651 Yin, J., Falconer, R.A., Che, Y., Probert, S.D., 2000. Water and sediment  
1566 652 movements in harbours. Appl. Energy 67, 341e352. PII: S0306-  
1567 653 2619(00)00030-1.  
1568  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1590  
1591  
1592  
1593

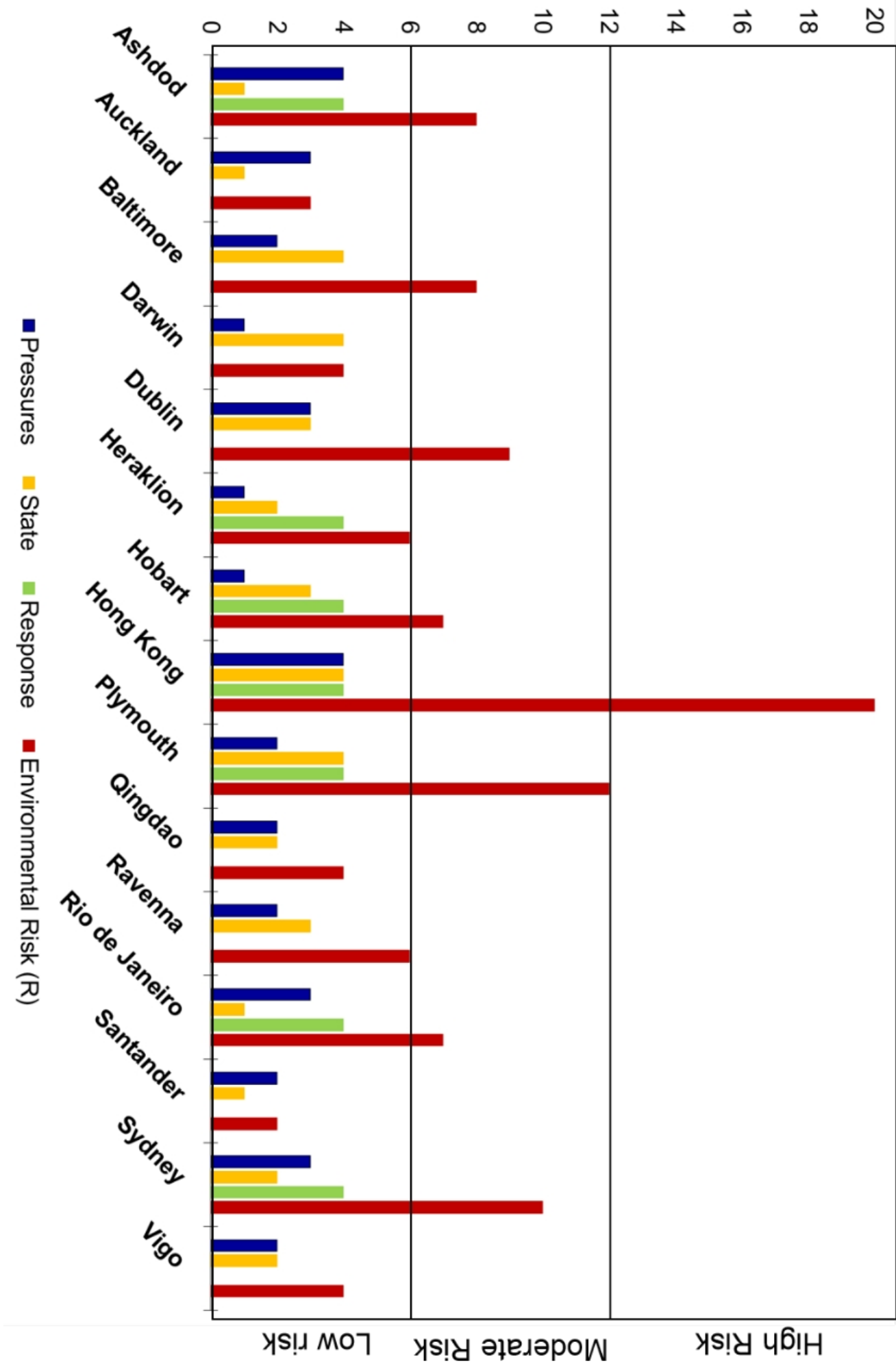


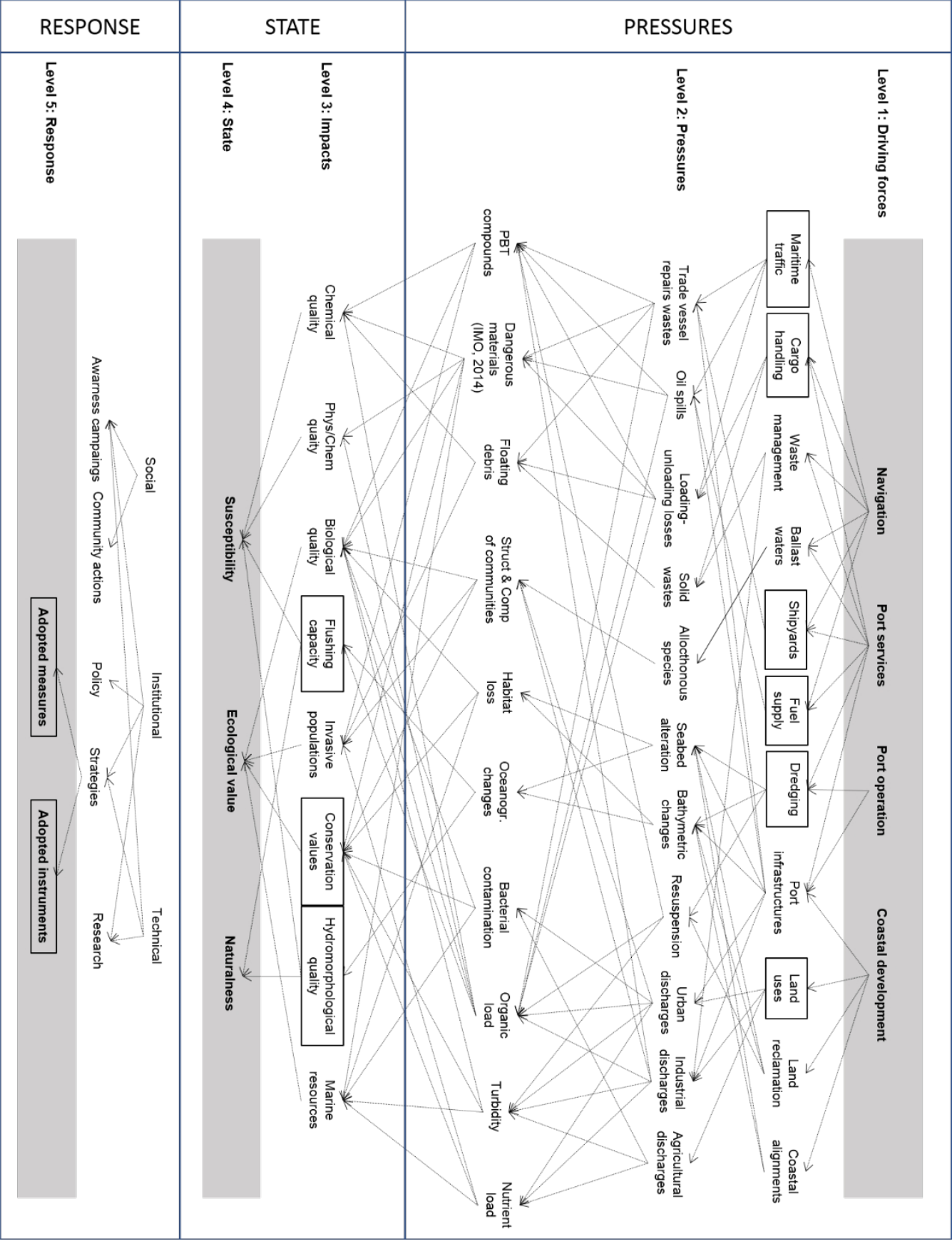








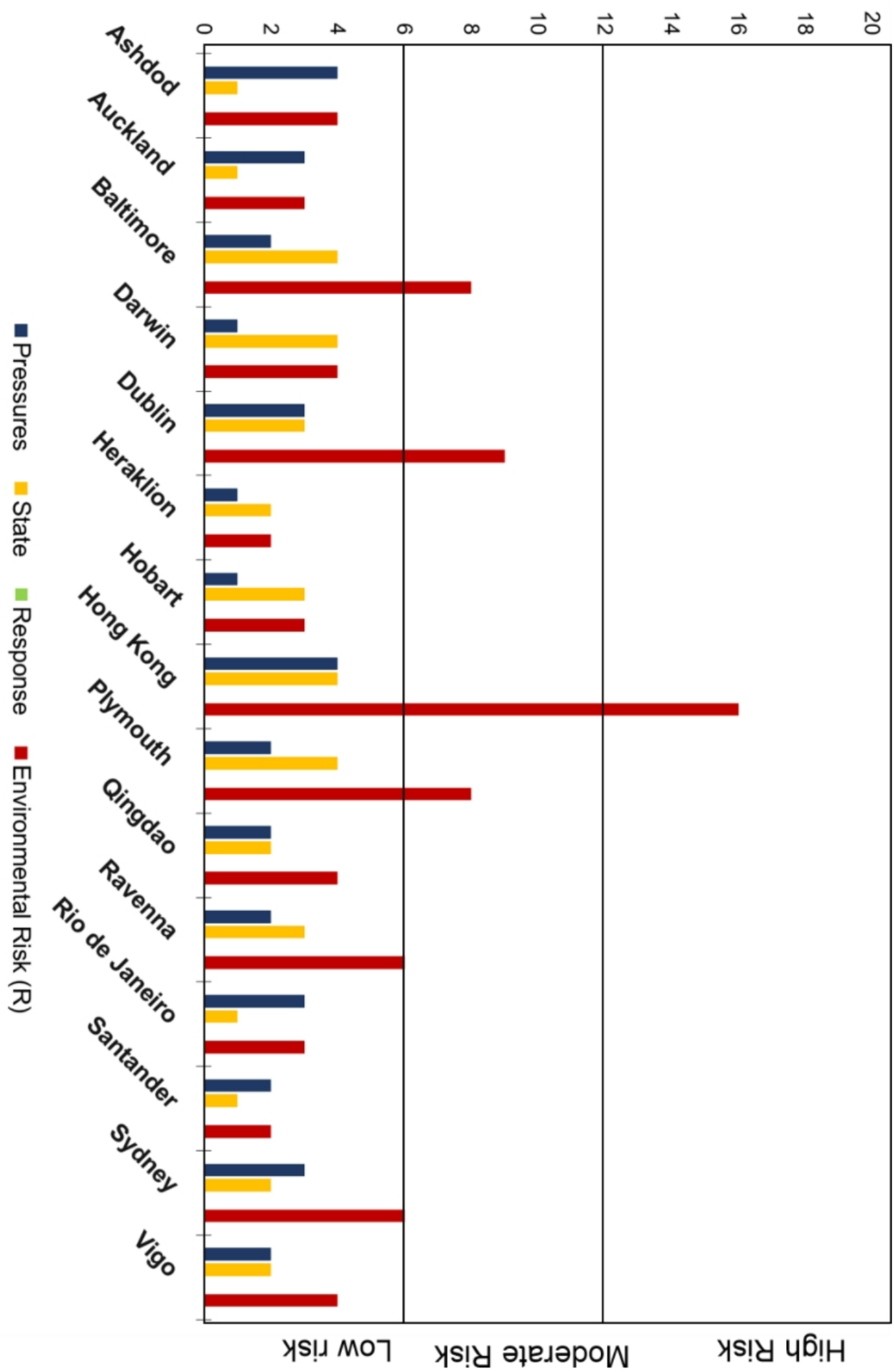






 Indicators

 Parameters



<b>General data</b>
Harbour's name: Postal address: Code: City: Country: web: phone: e-mail address:
<b>Hydromorphological characteristics:</b>
Entrance length (in meters): Average tidal range (in meters): Average depth (in meters): Depth at harbour entrance (in meters):
<b>Human pressures</b>
Number of trade vessels visits per year: Select which activities are developed in the harbour: <input type="checkbox"/> Fuel oil and diesel oil supplies <input type="checkbox"/> Major repair services <input type="checkbox"/> Dangerous/hazardous goods handling Frequency of dredging operations: <input type="checkbox"/> Continual <input type="checkbox"/> Periodic <input type="checkbox"/> No dredging
<b>Environmental management</b>
Number of Environmental Standard: Please, specify what kind of environmental standards (international certifications) are implemented in the marina: Select which environmental measures are implemented in the harbour: Measures: <input type="checkbox"/> Garbage disposal <input type="checkbox"/> Dirty ballast management <input type="checkbox"/> Waste management <input type="checkbox"/> Bilge management, Sewer Pump-Out <input type="checkbox"/> Oil management Specify any other environmental measure or instrument implemented in the harbour:

<b>Application scope</b>
<ol style="list-style-type: none"> <li>1. Access to GoogleEarth: <a href="https://www.google.es/intl/es/earth/">https://www.google.es/intl/es/earth/</a></li> <li>2. Introduce the name of the harbour in the seeker.</li> <li>3. Using Add -&gt; Add a polygon: draw the water surface where port activity takes place.</li> <li>4. Save the polygon as a .kmz and send it with this questionnaire filled out to: <a href="mailto:xxxxx.xxxx@unican.es">xxxxx.xxxx@unican.es</a></li> </ol>

--

**Paloma F. Valdor:** Conceptualization, Methodology, Data curation, Resources, Formal analysis, Visualization, Writing - Original Draft, Writing - Review & Editing

**Aina G. Gómez:** Conceptualization, Methodology, Supervision, Writing - Original Draft, Writing - Review & Editing

**Peter Steinberg:** Funding acquisition, Writing - Review & Editing

**Edwina Tanner:** Resources, Data curation, Writing - Review & Editing

**Antony M. Knights:** Resources, Data curation, Writing - Review & Editing

**Rochelle D. Seitz:** Resources, Data curation, Writing - Review & Editing

**Laura Airoidi:** Resources, Data curation, Writing - Review & Editing

**Louise B. Firth:** Resources, Data curation, Writing - Review & Editing

**Christos Arvanitidis:** Resources, Data curation, Writing - Review & Editing

**Massimo Ponti:** Resources, Data curation, Writing - Review & Editing

**Eva Chatzinikolaou:** Resources, Data curation, Writing - Review & Editing

**Paul R. Brooks:** Resources, Writing - Review & Editing

**Tasman P. Crowe:** Resources, Data curation, Writing - Review & Editing

**Alison Smith:** Resources, Data curation, Writing - Review & Editing

**Gonzalo Méndez:** Resources, Data curation, Writing - Review & Editing

**Aida Ovejero:** Resources, Data curation, Writing - Review & Editing

**Abilio Soares-Gomes:** Resources, Data curation, Writing - Review & Editing

**John A. Burt:** Resources, Data curation, Writing - Review & Editing

**Catriona MacLeod:** Resources, Data curation, Writing - Review & Editing

**José A. Juanes:** Corresponding author, Conceptualization, Methodology, Funding acquisition, Supervision, Project administration, Writing - Review & Editing