



PEARL

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Published in:

Environmental Science and Pollution Research

DOI:

[10.1007/s11356-022-23102-9](https://doi.org/10.1007/s11356-022-23102-9)

Publication date:

2022

Link:

[Link to publication in PEARL](#)

Citation for published version (APA):

Payne, M. R., & Turner, A. (2022). Remote sensing of boat abandonment using Google Earth. *Environmental Science and Pollution Research*, 0(0). <https://doi.org/10.1007/s11356-022-23102-9>

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2 **Remote sensing of boat abandonment using Google Earth**

3

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13 **Accepted 14 September 2022**

14 **<https://doi.org/10.1007/s11356-022-23102-9>**

15 **Abstract**

16 Abandoned boats represent a pervasive and growing problem in the coastal zone that have received
17 little regulatory or scientific attention. In this study, we show how Google Earth™ can be employed
18 to remotely identify abandoned boats and provide information on their size, age and condition.
19 Based on specified criteria for abandonment, a survey of southern England (1700 km in length)
20 reveals the presence of 266 boats that are mainly located in the intertidal zones of estuaries and
21 inlets and that are often contained within clusters. Boat length ranged from 2.6 to 60 m (median =
22 10.5 m) and since 2004 abandonment has been increasing at a rate of about eight per year. The
23 majority of boats appear to be of timber construction and exhibit evidence of damage and water-
24 sediment ingress. The environmental impacts are likely to be most significant where boats are
25 clustered on protected mudflats.

26

27 **Keywords**

28 Abandoned boats; Google Earth™; remote sensing; intertidal zone; antifouling paint; regulations

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31 **1. Introduction**

32 An abandoned boat is a vessel of any size (e.g., pleasure boat, fishing boat, cargo ship) that has been
33 given up by the legal owner without the intention of reclamation at a later date. Boats are
34 abandoned for a multitude of reasons, but it often comes down to costs. With a life span of around
35 30-45 years depending on the construction material, boats eventually come to their end of use and
36 need to be restored or disposed of safely and sustainably (European Commission, 2017). However,
37 both options are expensive, with the largest boat recycler in the UK, located in Portsmouth, quoting
38 around £100 per foot of hull length for dismantling and material recovery (Practical Boat Owner,
39 2020). To avoid these costs, owners may remove any means of identification before the boat is left
40 at its mooring, set adrift, sunk or concealed. These practices are often considered to be less
41 conspicuous and more acceptable at locations where abandoned boats already exist (Turner and
42 Rees, 2016).

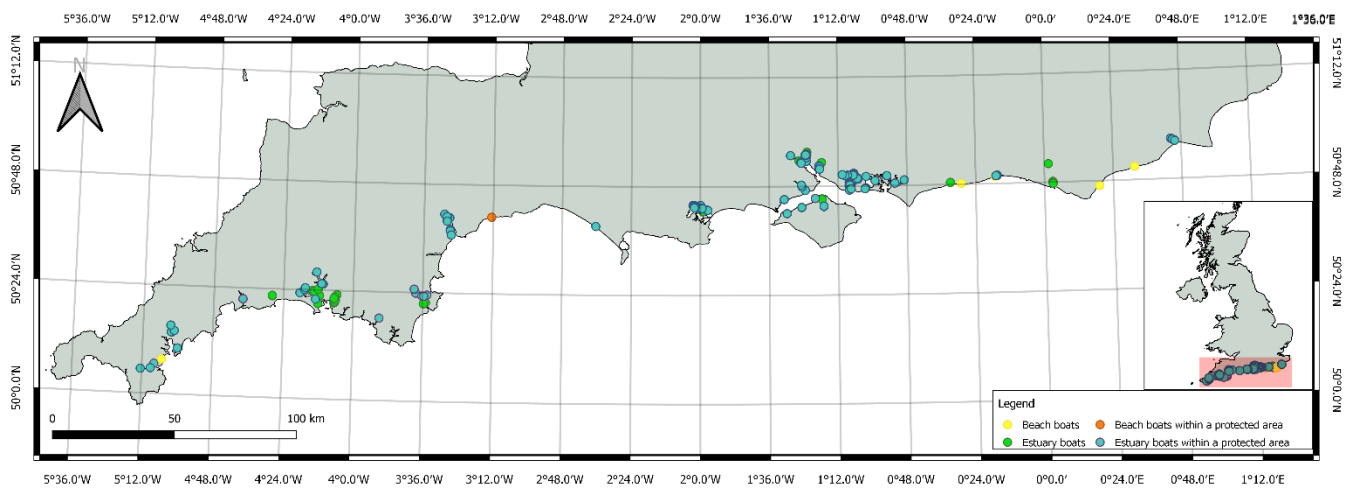
43 It appears to be illegal to abandon a boat in the UK but legislation is unclear and difficult to enforce.
44 The Thames Conservancy Act (1932) refers to removing or destroying “sunk or stranded” vessels at a
45 cost to the owner, and more recently, Environment Agency press releases mention removing
46 “unregistered” boats when they obstruct waterways, damage the environment (principally through
47 oil spillage) or have a significant impact on the aesthetics of the area (Environment Agency, 2017;
48 2018; 2019; 2020). Coupled with the costs mentioned above, there is, therefore, little incentive to
49 safely dispose of (Summerscales et end-of-life or unwanted boats and the problem is increasingly
50 reported in the literature al., 2016; Turner and Rees, 2016; Dibofori-Orji et al., 2019; Hopkinson et
51 al., 2021).

52 The Hydrographic Office houses a database on shipwreck locations around the UK derived from
53 insurance claims and boats flagged as a navigation problem (Admiralty Maritime Data Solutions,
54 2020). However, because abandoned boats are unreported, they are generally excluded. To this end,
55 we present a novel means of remotely and safely identifying and characterising abandoned boats in
56 the coastal zone through the use of Google Earth™ (GE). Specifically, we focus on the south coast of
57 England and systematically examine the scale and locations of the problem and how abandonment
58 has been evolving over the past two decades in order to identify any environments at risk and assist
59 in any remediation measures or decision-making.

60 GE is a powerful, interactive platform that superimposes satellite images, aerial photography and GIS
61 data onto a three-dimensional globe. It was introduced as Earth Viewer in 2001, changing to its
62 current name and becoming widely available to the public in 2005. The original imagery had a spatial
63 resolution of 15 m but this has been progressively improved to allow detail down to 30 cm or less to

64 be observed (Boardman, 2016). Because GE is freely available, easy to use, compatible with other
65 systems and data resources, and has a twenty-year timeline range, it is a popular tool in both
66 education and research (Mather et al., 2015; Malarvizhi et al., 2016). GE has been particularly useful
67 in physical and human geography and geology, with specific applications including the mapping,
68 monitoring and management of urban characteristics (San Emeterio and Mering, 2020), wetlands
69 (Hoffmann and Winde, 2010), glacial landforms (Darvill et al., 2014), coastal dunes (Turner et al.,
70 2021), droughts (Khan and Gilani, 2021) and shorelines (Warnasuriya et al., 2018).

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73 Figure 1: The area surveyed along the south coast of England from Rye to Land's End and the
74 location of boats abandoned in estuaries (and inlets) and on beaches.

75

76 2. Methods

77 Abandoned boats were identified between Rye, East Sussex, and Land's End, Cornwall (and including
78 the Isle of Wight), a stretch of coastline of about 1700 km in length and encompassing fourteen
79 unitary authorities (Figure 1). The coast comprises cliff-backed rocky shores, sandy beaches (often
80 backed by cliffs or dunes) and shingle ridges, interspersed with rias, estuaries and tidal inlets where
81 ports, harbours and various industries are often located. The entire coastline, including estuaries and
82 inlets up to their tidal limits, was surveyed with GE at an eye altitude of about 200 m and across the
83 range of dates for which suitable imagery was available (between 1999 and 2004 to 2020, and up to
84 fifteen different dates). Where abandoned boats were suspected, eye altitude was decreased to
85 between 50 and 100 m. Here, the approximate spatial resolution, estimated from the smallest

86 objects or details that could be observed and including distinctive boat parts whose precise
87 dimensions were established from a site visit to Hooe Lake (Figure 2), ranged from about 0.3 to 2 m.
88 Because of constraints on positional accuracy resulting from the use of images from different
89 satellites that are not orthorectified, coordinates are reported with a suitable precision (and to the
90 nearest whole second). Where available, imagery from Google Street View, an additional feature of
91 GE that provides interactive panoramas from positions along public streets, was inspected to gain
92 further details about specific boats.

93 Boats were defined as being abandoned if being they had been in precisely (or approximately) the
94 same position for a period of at least five years and/or met one or more of the following seven
95 criteria: partially or completely sunk; taking on water; lack of human activity on-board (e.g., tarps
96 and gear not moved and no evidence of renovation); plant growth or rust on the deck; damage with
97 no attempt to fix (e.g., collapsed wheelhouse, holes in the deck); inadequate mooring; evidence of
98 attempts to conceal (e.g., hidden under trees, located away from public access).

99 The construction material of each abandoned boat was noted if evident, and time series imagery
100 and the ruler tool in GE were used to determine the date of abandonment and length to the nearest
101 0.1 m or 0.2 m (based on the average of available measurements over time), respectively. The
102 former was defined as the year of first appearance of the boat if successive years of imagery were
103 available or the middle year if annual imagery was absent (i.e., if temporal resolution was more
104 irregular).

105 In many cases, identification of abandoned boats was straightforward in that a vessel would remain
106 at a specific location and undergo decay. Boats could first appear on imagery at a particular date or
107 be present throughout the whole time series recorded. In other cases, identification and
108 characterisation was more complex. This is exemplified by the GE imagery of the intertidal zone of
109 Hooe Lake, Plymouth, captured on four selected dates that illustrate the evolution in the number
110 and condition of several boats (Figure 2). Thus, boats A and B, of 20.4 m and 9.8 m in length,
111 respectively, are evident on the earliest imagery (December 2002). Boat A remains in the same
112 position throughout the time series to May 2020, but has begun to list by August 2016 and exhibits
113 considerable damage, including by fire, in the most recent image. In contrast, boat B has shifted its
114 precise location, either because of tidal currents or intervention during the mooring or
115 abandonment of other boats and structures, but is nevertheless classed as abandoned. Boats C and
116 D, of lengths of 20.7 m and 17.8 m, respectively, appear in imagery dated April 2007, and while the
117 latter is clearly abandoned and decaying, the former remains moored and appears to have
118 undergone recent modification. A subsequent visit to the location revealed that the boat is

119 undergoing restoration on an intermittent basis and is, not, therefore, classified as abandoned.
120 Boats E (32.0 m) and F (8.0 m) appeared between 2007 and 2010 and in 2016, respectively, and
121 while the former is in poor condition and taking in water, the latter appears to be securely moored
122 and in relatively good condition. Since boat F had been at the same location for only four years, the
123 principal criterion for abandonment was not, therefore, met.

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140 Figure 2: GE imagery of a region of Hooe Lake, Plymouth (50°21'22"N, 4°06'28"W), where boat
141 abandonment has been increasing over the past twenty years. Selected dates are shown as
142 month/year and boats labelled in each image are described in the text.

143

144



145 The condition of each abandoned boat identified in the most recent imagery of the coastline was
 146 categorised according to the criteria shown in Table 1, and examples of each category are illustrated
 147 in Figure 3.

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149 Table 1: Criteria used to categorise the condition of an abandoned boat.

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Condition	Criteria
Intact	Reasonable condition with minor cosmetic damage.
Damaged	Notable cosmetic or physical damage but no evidence of significant sediment or water ingress.
Partially submerged	Party below water or buried in sediment, often with notable damage.
Broken down	Completely (or almost completely) submerged and/or major damage to the whole structure.

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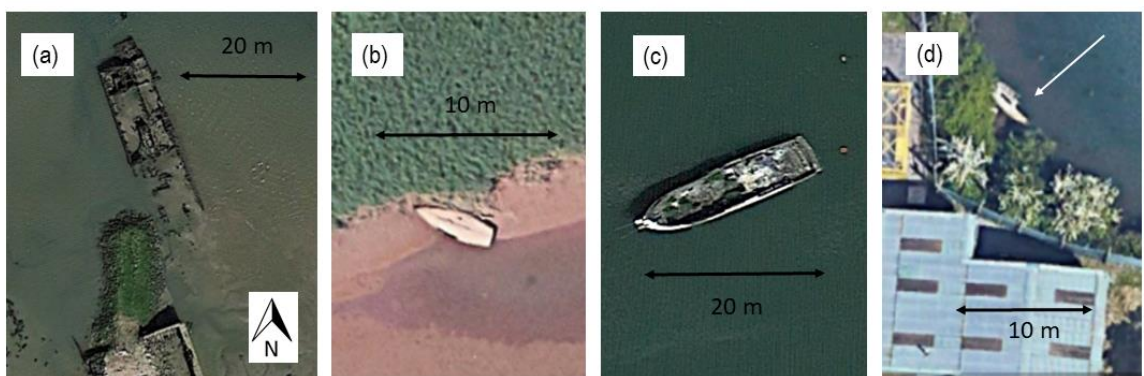
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168 Figure 3: GE images of (a) A broken down boat in Tipner Lake, Portsmouth (50°49'38.29"N,
 169 1°05'18.86"W), (b) an abandoned boat, hull facing upwards, in reasonable condition (intact) on the
 170 Exe Estuary (50°40'53.81"N, 3°28'03.65"W), (c) a damaged but floating boat on the Itchen Estuary

171 (50°55'08.46"N, 1°23'05.17"W), and (d) a partially submerged and concealed boat in a creek off
172 Southampton Water (50°53'39.19"N, 1°25'35.00"W).

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174 **3. Results and Discussion**

175 ***3.1. Spatial distribution of abandoned boats***

176 Overall, 266 abandoned boats were identified along the southern coast of England from GE imagery,
177 with the vast majority overlooked by the existing Wrecks Areas UK EEZ database (Admiralty
178 Maritime Data Solutions, 2020). This figure is equivalent to an average of one abandoned boat for
179 every 6.4 km of shoreline. However, the geographical distribution of the boats, shown in Figure 1,
180 reveals a high degree of spatial variation. Specifically, the majority of boats ($n = 257$) were
181 encountered on or in the intertidal mudflats and saltmarshes of estuaries and tidal inlets, with just
182 nine boats found above the high water line of (mainly) shingle beaches. This distribution results in
183 significant fractions of abandoned boats being located within protected sites, including 60.4% in
184 Ramsar Wetlands of International Importance and 68.7% in Sites of Special Scientific Interest (SSSI).
185 Presumably, the relatively high density of boats in mudflats and saltmarshes reflects limited public
186 accessibility (especially where the shoreline is industrialised) and ready concealment (and in
187 particular amongst saltmarsh vegetation), as well as the ability of fine, accreting sediment to
188 immobilise large structures.

189 Many of the boats on intertidal flats were also encountered in distinct clusters of up to twelve boats
190 (with clusters defined as at least two boats within 100 m of each other). The majority of clusters
191 were observed in the sheltered intertidal flats of estuaries and embayments around Portsmouth,
192 Southampton, Poole and Plymouth (Figure 1). In some cases, clusters appeared to develop over a
193 period of time through mooring aggregation, and as exemplified in Figure 4. Here, boats abandoned
194 before 1999 in the Itchen Estuary (and illustrated in 2004) were subsequently used for the mooring
195 and abandonment of newer vessels, resulting in the development of a dense cluster (and illustrated
196 in 2016).

197 Scattered clustering occurs when there is a growth of abandoned boats at a particular locality that
198 are not moored together. This type of clustering is evident in Hooe Lake, Plymouth (Figure 2), and at
199 Lytchett Bay in Poole Harbour (Figure 5) and has been reported in studies of the east coast of
200 England (Turner and Rees, 2016) and the Pacific and Caribbean territories of the US (Lord-Boring, et
201 al., 2004). Such locations are perceived to be convenient and acceptable because they evade any
202 punishment or other repercussions; consequently, they attract successive abandonments by the

203 same or different owners over a period of time. These locations often attract the dumping of other
204 structures that may or may not be related to boating activities (and as exemplified in Figure 5).

205 Event clustering is the sudden, mass abandonment of multiple boats at the same time resulting from
206 an incident. Mass abandonment has been reported in US territories because of extreme weather
207 events (Lord-Boring et al., 2004) but this is unlikely in the UK. More important here might be
208 closures of boating facilities or the withdrawal or replacement of a particular type of vessel. As an
209 example, a cluster of abandoned boats observed in Forton Lake, Portsmouth Harbour (Figure 6), was
210 attributed to an event that pre-dated GE imagery. Specifically, multiple boats were left when a
211 boatyard closed down in 1959, with additional boats being abandoned within the cluster since
212 (Karmy, 2009).

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221 Figure 4: GE imagery showing the evolution of a cluster of abandoned boats on the Itchen Estuary
222 ($50^{\circ}54'57''\text{N}$, $1^{\circ}22'55''\text{W}$) between (a) 2004 and (b) 2016.

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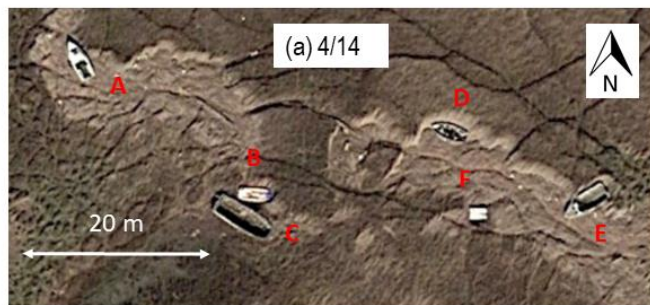
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Figure 5: GE image of a cluster of abandoned boats (A to E) in Lytchett Bay (50°43'53"N, 2°02'10"W).

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Note the presence of an additional, rectangular structure (F) that has been dumped at the location.

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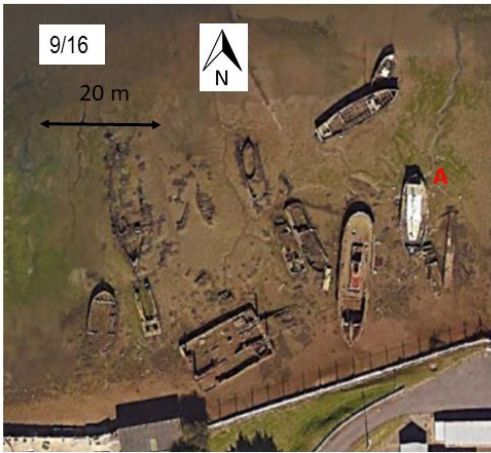


Figure 6: GE image of a cluster of abandoned boats in Forton Lake, Portsmouth Harbour (50°48'11"N, 1°07'57"W). Most boats, including those partly submerged in the sediment, were abandoned following the closure of a boatyard in 1959, but boat A appeared in 2015.

3.2. Characteristics of boats and dates of abandonment

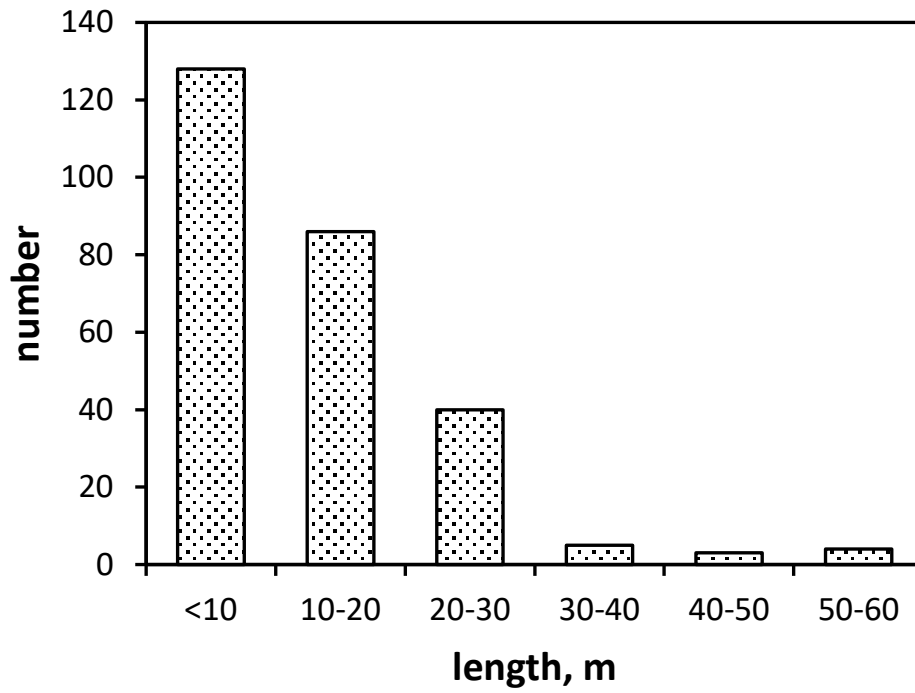
The size distribution of the abandoned boats identified in the present study is shown in Figure 7. Length ranged from 2.6 m to 60 m, with mean and median values of 13.4 m and 10.5 m, respectively, and frequency exhibited a reduction with increasing length. Regarding boat condition, and according to our criteria, 190 were broken down, 43 were damaged, 31 were partly submerged and two were intact. Amongst the abandoned boats, 95 could be defined in terms of their material of construction. Thus, based on colour, texture, panelling and decay, and, where available, imagery generated by Google Street View, 90 were identified as being of timber construction and five were identified as being of steel construction.

Local databases and historical accounts of shipwrecks and other underwater structures mention a few of the larger foreshore boats identified in the present study with abandonment dating back to 1945 (Langley and Small, 1988; The SHIPS Project, 2021). However, and despite GE imagery available since 1999 in some areas, the earliest date of recording across the entire coastal region surveyed was 2004. The year of abandonment since this date is shown in terms of cumulative frequency in Figure 8 and reveals a steady increase in the number of boats that averages 8.4 per year and a

269 relationship between cumulative frequency and year of abandonment that is defined by linear
270 regression with statistical significance. Note that this figure is not offset by boat recovery as none of
271 the abandoned vessels identified were removed from their locations during the time period
272 surveyed.

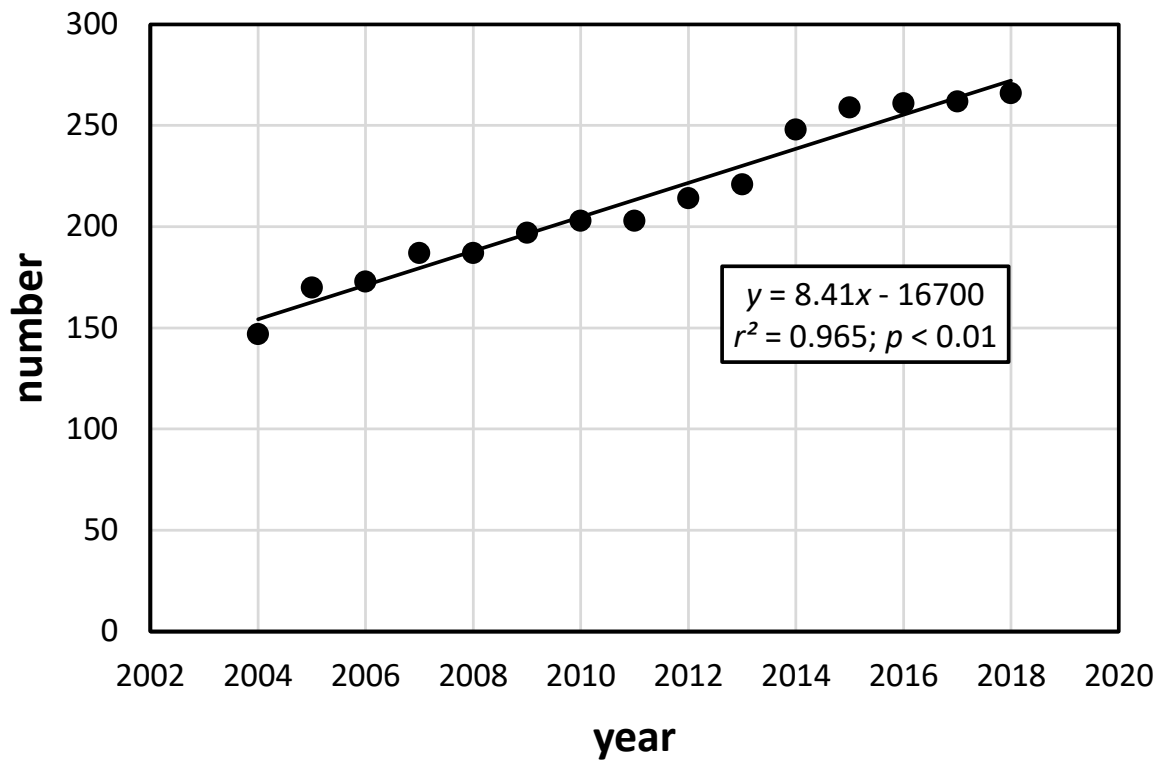
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276 Figure 7: Size distribution of the abandoned boats identified along the south coast of England.



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280 Figure 8: Cumulative frequency distribution of date of boat abandonment along the south coast of
281 England. The regression (solid line) is defined by the parameters annotated.

282

283 **3.3. Environmental impacts of boat abandonment**

284 Although GE is useful tool for the remote identification of abandoned boats, it is not able to provide
285 information on the significance of the problem. In the UK, for example, intervention from the
286 Environmental Agency will only take place if there is an immediate or visible navigation or pollution
287 threat. The latter is generally restricted to leaking oil (Turner and Rees, 2016), with impacts
288 associated with human safety, habitat loss and access to the shoreline not generally considered. A
289 longer-term pollution risk to the environment that is also overlooked by the authorities is the
290 gradual loss of antifouling hull paint particles into intertidal sediments (Rees et al., 2021; Hopkinson
291 et al., 2021). On older boats, antifouling paints may contain substances based on mercury, lead and
292 tributyltin that have been restricted or banned for decades (Lagerström et al., 2017; Turner, 2022).
293 Empirical evidence in the literature suggests that antifouling paint particles based on various
294 contemporary and historical formulations are toxic to many marine plants and animals at
295 environmentally realistic concentrations (Soroldoni, et al., 2018; 2020; Muller-Karanassos et al.,
296 2019). In this regard, some of the areas surveyed in the present study would appear to be at
297 particular risk. For instance, Lytchett Bay (Figure 6) is both an SSSI and a Ramsar Site and had the
298 highest concentration of abandoned boats across southern England (27 on about 1 km² of mudflats).
299 According to the Dorset Wildlife Trust (2021), the area is crucial for wading birds, fish, invertebrates
300 and amphibians and is also a destination for migrant birds which rely on invertebrates inhabiting the
301 mud for food.

302 **4. Conclusions**

303 GE provides a convenient and novel means of remotely assessing the scale and evolution of a
304 pervasive problem that has thus far received very little systematic or scientific attention. The
305 findings of this study across a 1700-km coastline of southern England reveal that boats are most
306 commonly abandoned in the intertidal zone of estuaries and inlets and, for a number of reasons,
307 abandonment is often observed in distinct clusters. Although the precise environmental impacts of
308 abandoned boats will require in situ monitoring, GE can help to identify sensitive or remote areas at
309 risk and regions where abandonment is rapidly increasing in order to assist with any decision- and
310 policy-making and guide intervention strategies.

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312

313 **Acknowledgements**

314 We acknowledge the use of Google Earth™ imagery in Figures 2 to 6.

315

316 **Declarations**

317

318 **Availability of data and materials**

319 The full dataset for the current study is available from the corresponding author on reasonable
320 request.

321 Not applicable

322 **Ethical approval**

323 Not applicable

324 **Consent to participate**

325 Not applicable

326 **Author contribution** MP: methodology, formal analysis, investigation, resources, data curation,
327 writing—original. AT: conceptualization, methodology, formal analysis, investigation, writing —
328 original draft, writing—review and editing, visualization, supervision, and project administration.

329 **Funding**

330 No funding was received for the study.

331 **Consent for publication** Not applicable

332 **Competing interests** The authors declare no competing interests

333

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