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# Ship incident risk around the heritage areas of Tubbataha and Banc d'Arguin

Christiaan Heij [a,*], Sabine Knapp [a], Ross Henderson [b], Edward Kleverlaan [c]

[a] Econometric Institute, Erasmus University Rotterdam, P.O. Box 1738, NL-3000 DR Rotterdam, The Netherlands
[b] 43 Bandjalong Crescent, Aranda, Canberra, ACT 2614, Australia
[c] 31 The Ridings, Cobham, KT11 2PU Surrey, UK

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ABSTRACT

Since the early 1990s, the International Maritime Organization has designated 14 Particular Sensitive Sea Areas that enjoy special protection because of their important attributes and vulnerability to potential harm by increasing shipping activities. The UN's Educational, Scientific and Cultural Organization identified two new candidate sites, the Banc d'Arguin national park in West Africa and the Tubbataha Reef national park in South-East Asia. We present various risk measures for ships trading in the areas of interest. Using a combination of data, we find increasing risk of ships trading through West Africa and South-East Asia in general as well as close to both heritage regions, supporting recommendations for increased levels of protection.



## 1. Introduction

In 1972, the UN's Educational, Scientific and Cultural Organization (UNESCO) adopted the 'Convention concerning the protection of the world cultural and natural heritage'. In 1994, the World Heritage Committee (WHC) launched a strategy to include exceptional marine features. The current list includes 46 marine world heritage sites in 35 countries. Although listing offers some safeguarding of marine areas, many stressors, such as international shipping, can threaten their conservation. Shipping activities have more than tripled since 1970 (United Nations Conference on Trade and Development, 2011), resulting in increased pollution risk for marine ecosystems with associated economic costs and damage to the environment. Since the early 1990s, the International Maritime Organization (IMO) has designated 14 sea areas as 'Particular Sensitive Sea Area' (PSSA) that enjoy special protection.

Recently, WHC has identified two of its world heritage sites as priority areas for possible designation as PSSA: the Banc d'Arguin national park in Mauritania and the Tubbataha Reef national park in the Philippines. Their location and passing ship traffic densities are shown in Fig. 1. Banc d'Arguin has an area of 1989 square kilometers and is a major breeding site for migratory birds. It contains some of the richest fishing waters in West Africa and serves as nesting grounds for the entire western region. It has at its northern extremity a fishing port that is recently expanding rapidly due to the growing oil and gas exploration and exploitation industry off the coast of Mauritania. The area is also adjacent to a major south-north oil shipping route. Tubbataha Reef has an area of 968 square kilometers and is listed as a 'Wetlands of international importance' under the Ramsar convention. It is a global center of marine biodiversity containing more than 600 fish, 360 coral, 11 shark, 13 dolphin and whale, and 100 bird species. These reefs also serve as a nesting ground for hawksbill and green sea

* Corresponding author.
*E-mail address:* heij@ese.eur.nl (C. Heij).

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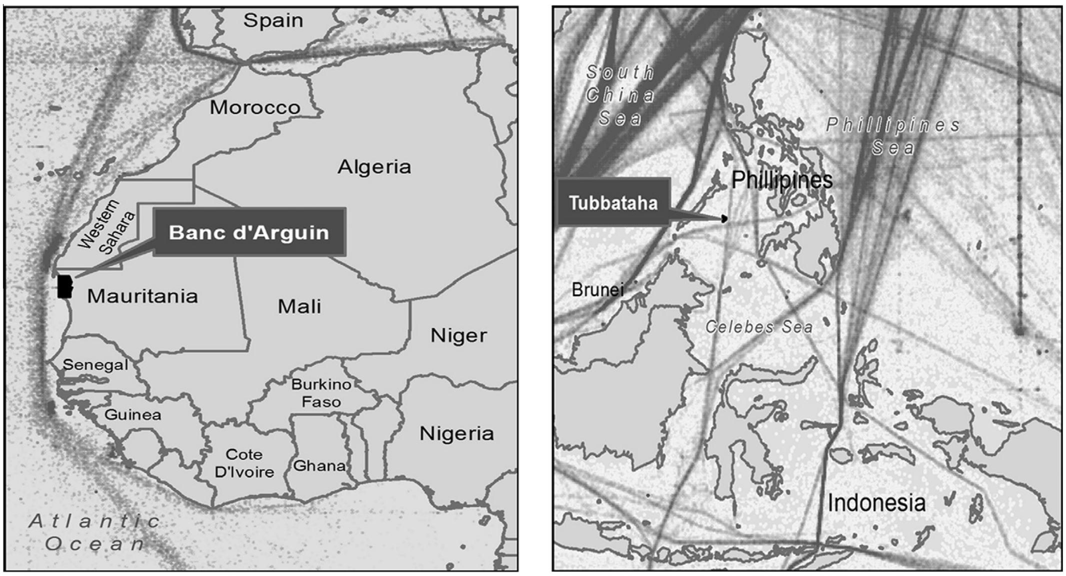


**Fig. 1.** Banc d'Arguin in Mauritania (left) and Tubbataha Reef in the Philippines (right) with indicators of shipping routes.

turtles. Tubbataha lies at the crossroads of several major shipping routes, including a major east–west archipelagic sea lane in the Philippines.

One of the criteria for a heritage site to be designated as PSSA under IMO is that it is vulnerable to damage by international shipping activities. This paper explores risk trends in the neighborhood of the two heritage sites. Total risk exposure is defined in Knapp (2013) as a combination of ship-specific risk, vessel traffic densities, physical environmental criteria, and ecological and socio-economic sensitivities. The physical environmental criteria can be split into forces related to ship-specific risk (like wind and waves) and hydrodynamic forces (such as currents corrected by tides and bathymetry coupled with wind and waves) that act upon drifting ships or hazardous substances on water in case of an incident. The analysis presented here concentrates on ship-specific risk, including location-specific effects of wind and waves, building on Knapp et al. (2011b). Hydrodynamic aspects are indirectly accounted for by selecting a boundary of 100 nautical miles around the two heritage areas, corresponding to a five-day intervention time to assist drifting ships or to mobilize oil pollution response. Consequences of incidents are evaluated by insurable (mostly socio economic) damages in terms of the monetary value at risk, building on Knapp et al. (2011a) and Heij and Knapp (2012). Our analysis extends previous works of Eide et al. (2007), Admiral Danish Fleet (2012), and Det Norske Veritas (2013) that do not account for ship-specific risk, effects of wind and waves, or monetary risk. Ecological damages fall beyond the scope of this paper.

## 2. Data

The dataset contains information on various types of shipping incidents and related risk factors, covering January 1979 to July 2007. The main incident data sources are Lloyd's Register Fairplay, Lloyd's Maritime Intelligence Unit, and the IMO. As the data providers use different classifications of incidents, they were manually reclassified for compatibility with the internationally agreed definitions used by International Maritime Organization (2000) for very serious (including total loss), serious, and less serious incidents. We account for all incidents that can lead to pollution, such as collisions, contact, stranding and groundings, main engine blackouts (which can lead to drift grounding), capsizing, hull-related failures, flooding, and foundering. These incidents are classified as either serious or very serious; of the less serious incidents we only include those involving pollution. Pollution occurs for 367 out of the 3561 very serious incidents, for 141 out of 3691 serious incidents, and for 9 less serious incidents.

Each observation is for a specific vessel at a specific time and location and contains information on whether an incident occurred (and if so, of what type) as well as on a number of risk factors, including ship-particular data and location-specific oceanographic data at the time of observation. This information was obtained by merging various data sources by means of the vessel-specific IMO number. The ship-particular data include ship particulars from IHS Fairplay, ship safety inspections (Bijwaard and Knapp, 2009), and relevant industry vetting inspections. Changes in ship particulars (flag, class, and ownership) are taken into consideration for the 360 days prior to observation. The same applies for previous inspection history in terms of detentions, deficiencies, port state control inspections, and International Safety Management (ISM) audits. Macro-economic conditions are included by deflated average earnings per ship type available on a monthly basis from the Shipping Intelligence Network of Clarksons.

**Table 1**
Number of observations.

| Period | 1979–2007 | 1979–1998 | 1999–2007 |
|---|---|---|---|
| *Mean annual number of individual ships* | | | |
| World commercial fleet (Total) | 82,018 | 78,141 | 90,635 |
| Voluntary Observing Ships (VOS) | 6859 | 7162 | 6185 |
| South-East Asia (SEA) | 915 | 1031 | 657 |
| West Africa (WA) | 944 | 1070 | 664 |
| SEA and WA | 1859 | 2101 | 1321 |
| Tubbataha | 83 | 94 | 57 |
| Banc d'Arguin | 85 | 96 | 59 |
| Tubbataha and Banc d'Arguin | 167 | 190 | 116 |
| *Percentage shares of ships* | | | |
| VOS (of Total) | 8.5 | 9.2 | 6.9 |
| SEA and WA (of Total) | 2.3 | 2.7 | 1.5 |
| SEA and WA (of VOS) | 26.8 | 29.3 | 21.5 |
| Tubbataha (of SEA) | 9.0 | 9.2 | 8.6 |
| Banc d'Arguin (of WA) | 9.0 | 9.1 | 8.7 |
| *Number of observations* | | | |
| Months | 343 | 240 | 103 |
| Estimation (SEA and WA large) | 3,433,818 | 2,608,760 | 825,058 |
| SEA and WA | 905,601 | 684,189 | 221,412 |
| Tubbataha and Banc d'Arguin | 16,872 | 13,928 | 2944 |
| *Percentage shares of observations* | | | |
| Months | 100.0 | 70.0 | 30.0 |
| Estimation (SEA and WA large) | 100.0 | 76.0 | 24.0 |
| SEA and WA (of Estimation) | 26.4 | 26.2 | 26.8 |
| Tubbataha and Banc d'Arguin (of SEA and WA) | 1.9 | 2.0 | 1.3 |

Vessel positions and oceanographic data on wind speed and wave and swell data have been obtained from the International Comprehensive Ocean–Atmosphere Data Set (ICOADS), the largest available compilation of surface meteorological observations from voluntary observing ships (VOS). These observations are made by the ship's crew or by instruments on board. Reports are transmitted to VOS ideally every six hours, but many vessels report less frequently, like once a day or only at irregular time intervals. The reported variables have been corrected for biases due to differences in measurement techniques.[1]

Table 1 provides an overview of the observations, which are split in a base period, 1979–1998, and recent years, 1999–2007 to evaluate trends in risk. The data contain well over three million vessel–time–location specific observations of VOS vessels, with share of the world commercial fleet declining from 9.2% in the base period to 6.9% in recent years. The locations lie within larger regions in West Africa and South-East Asia than around Mauritania and the Philippines indicated in Fig. 1. These smaller regions are used to assess the risk levels around the heritage areas and, compared to the larger regions, they represent 26.4% of the observations and 26.8% of VOS vessels. Further, two regions close to the heritage areas are defined by a radius of 100 nautical miles (185.2 km) from the shoreline of Tubbataha or Banc d'Arguin, corresponding to a five-day response time for oil spill response vessels to arrive. These two heritage areas are relatively small, accounting to 1.9% of the observations and 9.0% of vessels.

## 3. Model-based risk

Ship incident risk is evaluated in terms of incident probabilities and associated monetary costs. Separate incident probability models are estimated per ship type (general cargo, dry bulk, tanker, container, passenger, and other), per type of incident (very serious, serious, and pollution), and for the two regions of interest (South-East Asia and West Africa). Due to lacking data, pollution incident models were estimated only for tankers for both regions and for general cargo ships and dry bulk carriers in South-East Asia. The resulting 28 models are each specified and estimated following Knapp et al. (2011b). The incident probability is modeled as a logit specification containing the following risk factors: ship particulars (age, size, classification society, flag state, and past changes of classification, flag, and owner), ship safety indicators (inspection history by port state control authorities, industry, flag state, and ISM audits, and detention and deficiency history), an economic indicator (earnings in shipping), and meteorological information (month of the year, wind strength, and significant wave height).

Incident probabilities can be translated to some extent in monetary terms using insured values per vessel, following Knapp et al. (2011a) and Heij and Knapp (2012). Socio-economic damage is evaluated in terms of hull and machinery dam-

[1] The method described by Thomas et al. (2005) homogenizes wind speeds, and the method of Gulev and Grigorieva (2006) corrects wave and swell data to get the so-called significant wave height.

age, cargo loss, third party liability, pollution, and loss of life. Notwithstanding its importance, ecological damage is not included because it is difficult to express in monetary terms. For a given vessel observation, let $V_j$ be the monetary value of damage type $j$, then $\sum_{j=1}^{5} V_j$ is the total insurable value (TIV). This can be seen as the costs of total loss. As most incidents only involve partial losses, the monetary value at risk (MVR) is defined as

$$\mathrm{MVR} = p_{inc} \times \sum_{j=1}^{5} p_j V_j,$$

where $p_{inc}$ is the probability of an incident and $p_j$ is the conditional probability of damage type $j$ in case of an incident. The numerical values of these conditional probabilities and damages are taken from Knapp et al. (2011a).

The model-based incident probabilities and their associated monetary values cannot be compared directly across regions and ship types because of differences in observation frequency. This frequency varies among vessels and among days, with average per region and ship type ranging from 0.64 to 7.59 times per day. Many of the incident data have much lower frequencies, down to a single vessel observation for the full data period. The oceanographic variables are location-specific and should not be aggregated since local weather conditions can change frequently. The probabilities obtained from each logit model are scaled to a common time scale, basically by multiplying the logit probabilities by the average observation frequency. More precisely, let $q$ denote the risk for a single (vessel–location dependent) unit of time, then the risk $p$ for $T$ units of time is obtained as follows. The probability not to have an incident in a single unit of time is $1 - q$, and the probability not to have an incident in $T$ units of time is $(1 - q)^T$. Therefore, $1 - p = (1 - q)^T \approx 1 - Tq$ as the value of $q$ is small in our applications, so that $p \approx Tq$. If the observation frequency is for example 7.59 per day, then a day contains $T = 7.59$ units of time and the risk for a day is $p \approx 7.59q$. After rescaling, the common time scale does not refer to an easily identifiable clock-time period because many of the incidents consist of a single observation per vessel with undefined observation frequency. Therefore the incident risks are expressed in relative terms, as risk in recent years relative to the base period. As each model is estimated for the full period, the probabilities can be compared among sub-periods as they share a common time unit. Yearly probabilities involving an extra calibration step relating the scaled model-based incident probabilities to the empirical yearly incident rates for the world fleet can also be calculated for each of the models separately. Finally, sample means within each of the models employ weighted sums, using weights equal to the inverse of the vessel-day specific observation frequency, to prevent over-representation of high-observation ships.

## 4. Change of risk over time

As the number of observations for the zones within 100 nautical miles of the heritage regions is limited, we focus mostly on the risk in the larger areas around these two regions. The development of average incident probabilities and MVR is displayed in Fig. 2 for six consecutive periods and for three ship types (general cargo vessels, dry bulk carriers, and tankers). The two risk measures are expressed as indices, relative to the mean risk in the base period (January 1979 to December 1983), for 1984–1988, 1989–1993, 1994–1998, 1999–2003, and 2004–2007. Because of data limitations, pollution incident probabilities are available for tankers, and additionally for South-East Asia for general cargo and dry bulk vessels, whereas the MVR of pollution is available only for tankers. Incident probabilities and monetary values at risk show general tendencies to increase over time. Pollution risk is a particular hazard to the heritage regions, and pollution probabilities and their associated MVR have increased in recent years. Risk levels for the six periods were compared using parametric (ANOVA) tests and non-parametric (Kruskal–Wallis) tests for 56 cases in terms of the probabilities and MVR for each of the 28 combinations of region, ship type, and incident type. The differences between the periods are highly significant in almost all cases.

As we are mainly interested in recent risk trends, we aggregate the six periods to two – the base, 1979–1998, and recent years, 1999–2007. Table 2 shows mean values of incident probabilities and of monetary values at risk in the recent period relative to the base; values above one indicate a recent increase of risk, and those below a decrease. These risk increases are shown for South-East Asia (near the Philippines) and West Africa (near Mauritania), and for the 100 nautical miles zones around the two heritage regions. Nearly all risks measures have increased over time, with MVR increasing more substantially than incident probabilities. We find that the probability of pollution incidents increased by about 60% for South-East Asia and 25% for West Africa, and the associated MVR for tankers doubled for both regions. The pollution risk for the two heritage sites increased even more, in terms of pollution incident probabilities as well as the associated MVR. In the majority of cases, conventional comparison-of-mean $t$-tests show that risk increases are highly significant. Notwithstanding small sample sizes, pollution risk increased significantly also for the class of tankers passing through the heritage sites.

## 5. Magnitude of yearly risk

Turning to annual monetary risk, which is often believed to be more relevant for policy making, the vessel risk exposure to total loss incidents is defined as VREI = $P \times$ TIV, where $P$ is the annual probability of a very serious incident, and TIV is the total insured value. This differs from MVR in that it measures loss of all value, whereas MVR down-weights the various values by means of their conditional damage probabilities. VREI is an approximation of actual risk, involving both over-estimation, because not all insurable value may be lost at each very serious incident, and under-estimation, because it neglects the

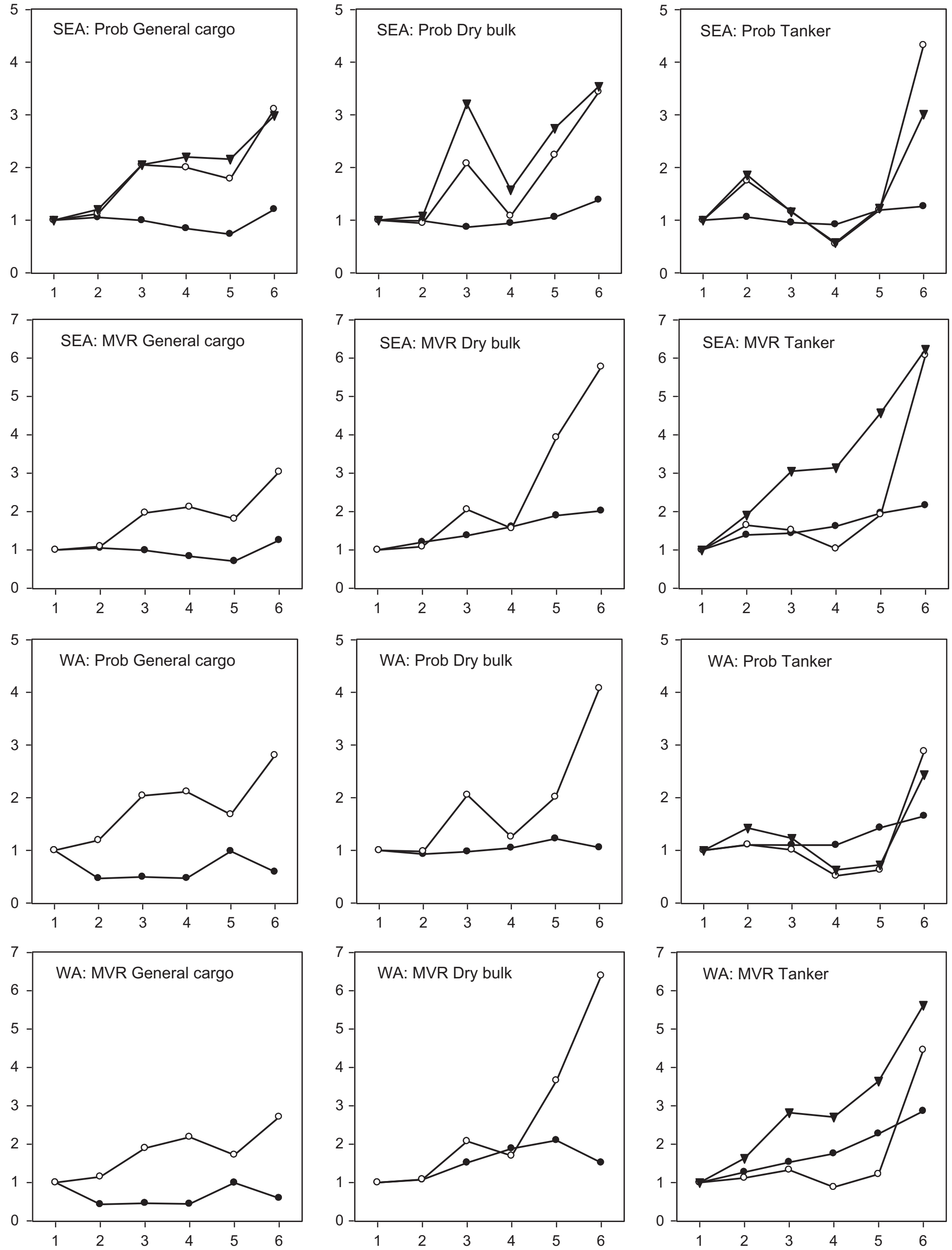


**Fig. 2.** Mean incident probability index ("Prob") and mean monetary value at risk index ("MVR") for three ship types and six periods, for South-East Asia (SEA) and West Africa (WA). *Note*: Index values are 1 for base period 1, 1979–1983; the other periods are 2 for 1984–1988, 3 for 1989–1993, 4 for 1994–1998, 5 for 1999–2003, and 6 for 2004 to 2007; closed bullet for very serious incidents, open bullet for serious incidents, and triangle for pollution incidents.

damage from serious incidents that do not qualify as very serious. For pollution incidents, only the insurance coverage for oil pollution is taken into account for the insured value.

Table 3 shows average annual incident probabilities and values of TIV and VREI corrected for inflation for 1999–2007 and 1979–1998. The relationship VREI = $P \times$ TIV holds true for each individual vessel observation, but not for average values. Most notable for South-East Asia is the increased pollution risk of tankers, where the yearly VREI per tanker increased from about $25,000 in the base period to over $45,000 in recent years. This increase is due both to increased incident probability from 0.163% to 0.229% per year, and to higher insurable value from $10.7 to $13.1 million. For West Africa, VREI has in-

**Table 2**
Relative increase of incident probabilities (1999–2007 compared to 1979–1998).

| | Observations | Probability | | | Monetary value at risk | | |
|---|---|---|---|---|---|---|---|
| | | Very serious | Serious | Pollution | Very serious | Serious | Pollution |
| *South-East Asia* | | | | | | | |
| General cargo | 122,087 | 0.91 | 1.55$^{***}$ | 1.61$^{***}$ | 0.91 | 1.55$^{***}$ | – |
| Dry bulk | 60,690 | 1.22$^{**}$ | 1.95$^{***}$ | 1.64$^{***}$ | 1.44$^{***}$ | 2.99$^{***}$ | – |
| Tanker | 116,361 | 1.24$^{***}$ | 2.02$^{***}$ | 1.60$^{***}$ | 1.46$^{***}$ | 2.53$^{***}$ | 2.16$^{***}$ |
| All types | 471,127 | 1.01 | 1.72$^{***}$ | 1.61$^{***}$ | 1.29$^{***}$ | 2.20$^{***}$ | – |
| All Tubbataha | 8549 | 0.88 | 1.86$^{**}$ | 5.90$^{**}$ | 1.02 | 1.92$^{***}$ | – |
| Tankers Tubbataha | 1497 | 1.27 | 13.04$^{*}$ | 10.69$^{*}$ | 1.12 | 8.77$^{**}$ | 4.42$^{**}$ |
| *West Africa* | | | | | | | |
| General cargo | 138,362 | 1.37$^{*}$ | 1.39$^{***}$ | – | 1.44$^{***}$ | 1.41$^{***}$ | – |
| Dry bulk | 55,555 | 1.19$^{***}$ | 1.87$^{***}$ | – | 1.37$^{***}$ | 2.87$^{***}$ | – |
| Tanker | 98,773 | 1.39$^{***}$ | 1.60$^{***}$ | 1.25$^{**}$ | 1.73$^{***}$ | 2.16$^{***}$ | 2.01$^{***}$ |
| All types | 434,474 | 1.16$^{***}$ | 1.51$^{***}$ | – | 1.45$^{***}$ | 1.97$^{***}$ | – |
| All Banc d'Arguin | 8323 | 0.98 | 2.17$^{***}$ | – | 1.07 | 2.70$^{***}$ | – |
| Tankers Banc d'Arguin | 1409 | 1.00 | 4.55 | 3.21$^{*}$ | 1.08 | 6.78$^{*}$ | 4.67$^{*}$ |

*Notes*: Probabilities from logit models per region and ship type are corrected by the mean observation frequency; in computing sample means, probabilities are down-weighted per individual ship and day by the ship-day specific observation frequency.
$^{*}$ Significance at 0.05 level.
$^{**}$ Significance at 0.005 level.
$^{***}$ Significance at 0.0005 level.

**Table 3**
Mean annual vessel risk exposure of total loss incidents.

| | | | Very serious incident | | | Pollution only | | |
|---|---|---|---|---|---|---|---|---|
| | Variable Units | observations | *P* 0.001 | TIV 1,000,000 | VREI 1000 | *P* 0.001 | TIV 1,000,000 | VREI 1000 |
| *South-East Asia* | | | | | | | | |
| General cargo | Base | 99,714 | 9.00 | 50.15 | 472.92 | 0.53 | 10.38 | 3.85 |
| | Recent | 22,373 | 7.85 | 54.00 | 408.78 | 0.76 | 11.95 | 4.48 |
| Dry bulk | Base | 44,838 | 2.82 | 46.65 | 122.48 | 0.24 | 10.44 | 2.58 |
| | Recent | 15,852 | 3.29 | 49.64 | 167.56 | 0.44 | 11.70 | 4.88 |
| Tanker | Base | 90,655 | 5.40 | 44.23 | 231.82 | 1.63 | 10.73 | 25.42 |
| | Recent | 25,706 | 5.69 | 52.77 | 300.12 | 2.29 | 13.09 | 46.08 |
| All | Base | 353,491 | 5.51 | 47.30 | 269.91 | 1.02 | 10.88 | 8.72 |
| | Recent | 117,636 | 4.95 | 47.71 | 255.01 | 1.48 | 11.34 | 13.06 |
| All Tubbataha | Base | 7028 | 5.55 | 48.16 | 249.55 | 0.47 | 10.96 | 1.52 |
| | Recent | 1521 | 5.16 | 41.81 | 198.31 | 2.73 | 9.31 | 19.09 |
| *West Africa* | | | | | | | | |
| General cargo | Base | 113,617 | 3.52 | 39.87 | 140.69 | | – | |
| | Recent | 24,745 | 4.18 | 42.18 | 160.48 | | – | |
| Dry bulk | Base | 41,500 | 1.31 | 32.67 | 42.42 | | – | |
| | Recent | 14,055 | 1.48 | 34.02 | 48.84 | | – | |
| Tanker | Base | 75,796 | 3.34 | 34.24 | 115.25 | 1.49 | 6.06 | 12.20 |
| | Recent | 22,977 | 4.19 | 39.43 | 164.19 | 1.84 | 7.94 | 17.26 |
| All | Base | 330,698 | 2.59 | 35.52 | 94.71 | 0.89 | 5.71 | 3.98 |
| | Recent | 103,776 | 2.75 | 36.57 | 104.67 | 1.22 | 5.99 | 5.23 |
| All Banc d'Arguin | Base | 6900 | 2.23 | 37.42 | 87.97 | 0.56 | 6.09 | 0.73 |
| | Recent | 1423 | 2.17 | 32.97 | 75.62 | 1.24 | 4.45 | 1.40 |

*Notes*: The table reports weighted mean values, corrected for varying observation frequencies.
*P* is the annual probability multiplied by 1000 of a very serious incident (assuming total loss).

creased for nearly all ship types. For pollution risk, the yearly VREI per tanker increased from about $12,000 in the base period to about $17,000 in recent years, because of increases in both the incident probability (from 0.149% to 0.184% per year) and the insurable value (from $6.1 to $7.9 million). VREI values for West Africa are smaller than for South-East Asia, because of relatively smaller values of both TIV and incident probabilities. For all ship types aggregated, vessels travelling through South-East Asia have 30% higher value and nearly twice as high incident probability as compared to West Africa. For recent years, the average VREI for all ship types combined is $255,000 for South-East Asia and $105,000 for West Africa, and the average TIVs are $47.7 and $36.6 million.

The table also shows the risk of ships trading within 100 nautical miles of the two heritage regions. The results show no increase for very serious incidents, whereas pollution risk increased because of increased pollution incident probabilities. These results for the two heritage regions are less reliable, as the number of observations is relatively small.

## 6. Conclusion

This paper evaluates various risk dimensions associated with shipping activities around two UNESCO heritage areas, Tubbataha and Banc d'Arguin. The analysis includes ship-specific risk as a proxy of the safety quality of vessels trading in the area, and it also incorporates oceanographic factors like wind speed and wave height. The risk indicators consist of incident probabilities and their associated monetary consequences, which account indirectly for socio-economic damages.

The main conclusion is that incident probabilities and monetary value at risk have increased in recent years; the probability of pollution in 1999–2007 increased by about 60% for South-East Asia and 25% for West Africa compared to 1979–1998, and the associated MVR for tankers has doubled for both regions. The increase of pollution risk close to the two heritage sites is even larger. In terms of annual vessel risk exposure of total loss incidents, the average annual value for 1999–2007 is $255,000 for South-East Asia and $105,000 for West Africa, with average insurable values of $47.7 and $36.6 million. The VREI for pollution has increased because annual pollution probabilities per tanker rose from 0.163% in the base period to 0.229% in recent years for South-East Asia, and from 0.149% to 0.184% for West Africa, and because TIV increased due to larger vessels.

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