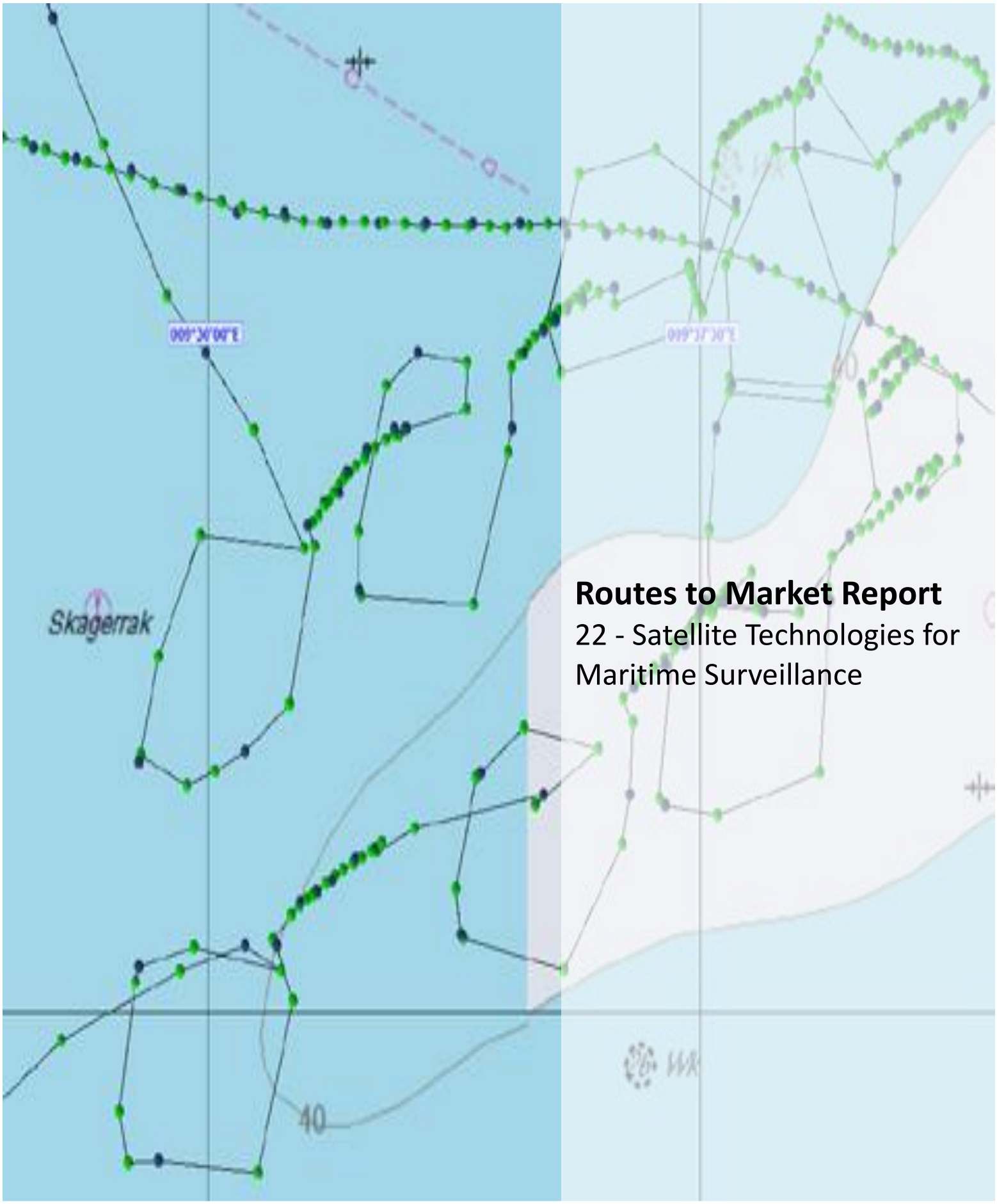


Routes to Market Report

22 - Satellite Technologies for Maritime Surveillance

Innovate UK

NICK LAMBERT ASSOCIATES

CATAPULT Satellite Applications

Contents

1. Executive summary

The emerging **Blue Economy** provides growing opportunities for satellite technologies in services and solutions that enable sustainable growth within the maritime environment, specifically: to **improve marine knowledge** to enhance access to information about the sea; for **maritime spatial planning** to ensure an efficient and sustainable management of activities at sea; and to allow **integrated maritime surveillance** to give authorities a better picture of what is happening in the seas and oceans under their governance.

For each of these components, **satellite positioning**, **navigation**, **Earth Observation** and **communications** are key enabling technologies. Particularly important is the requirement for resilient, ubiquitous, high-quality connectivity for large volumes of data.

Around 80% of global trade by volume, and over 70% by value, is carried by ships and handled by ports worldwide. There are over 50,000 merchant ships trading internationally, transporting every kind of cargo. **The world fleet is registered in over 150 nations, and manned by over a million seafarers**.

World seaborne trade (by tonnage) is dominated by Asia, with the Americas and Europe vying for second place in the global league table. **Asian ports also dominate** league tables for vessel port calls. Developed countries own 60% of seagoing merchant vessels, with developing countries in Asia claiming 36%.

The UK maritime sector is worth £11bn to the economy and employs 100,000 people. **Global Navigation Satellite Systems** and **Satellite Earth Observation** are important to maritime customers facing global economic challenges.

The world in 2030 will be shaped by powerful global trends. **Population growth** and **increasing urbanisation** will lead to increasing difficulties in providing adequate amounts and quality of food and water and increasing expectations with regard to health, safety, security and environmental impact. **The two possibly biggest drivers are climate disruption and digitalisation.**

The aquaculture market is expected to be worth $202.96 Billion by 2020. China was the largest market for aquaculture in 2013, accounting for about 53% of global market share. Asia Pacific (excluding China) was the second largest market.

Roughly one in every five fish landed around the world is caught illegally. Nearly 3% of the world's oceans are now classified as Marine Protection Areas, and having developed such policies, **the challenge shifts to devising cost effective ways to enforce them**. Satellite capabilities have a strong role to play here.

The global maritime border and security market is estimated to grow from $16.71 billion in 2016 to $23.67 billion by 2021, at a CAGR of 7.2%, driven by increasing incidents of piracy and marine terrorism on vessels, ports, and other critical infrastructure. **The surveillance and tracking technology segment is expected to have the largest market share and dominate the maritime safety market from 2016 to 2021.** North America is expected to dominate this market. Earth Observation and satellite connectivity and positioning are increasing in importance.

The global market for water quality sensing and monitoring equipment is expected to reach $6.49 billion by 2019, growing at a CAGR of 7.2% thanks to advancements in aquatic sensors such as salinity, turbidity, and flow sensors. China and India are estimated to be the fastest-

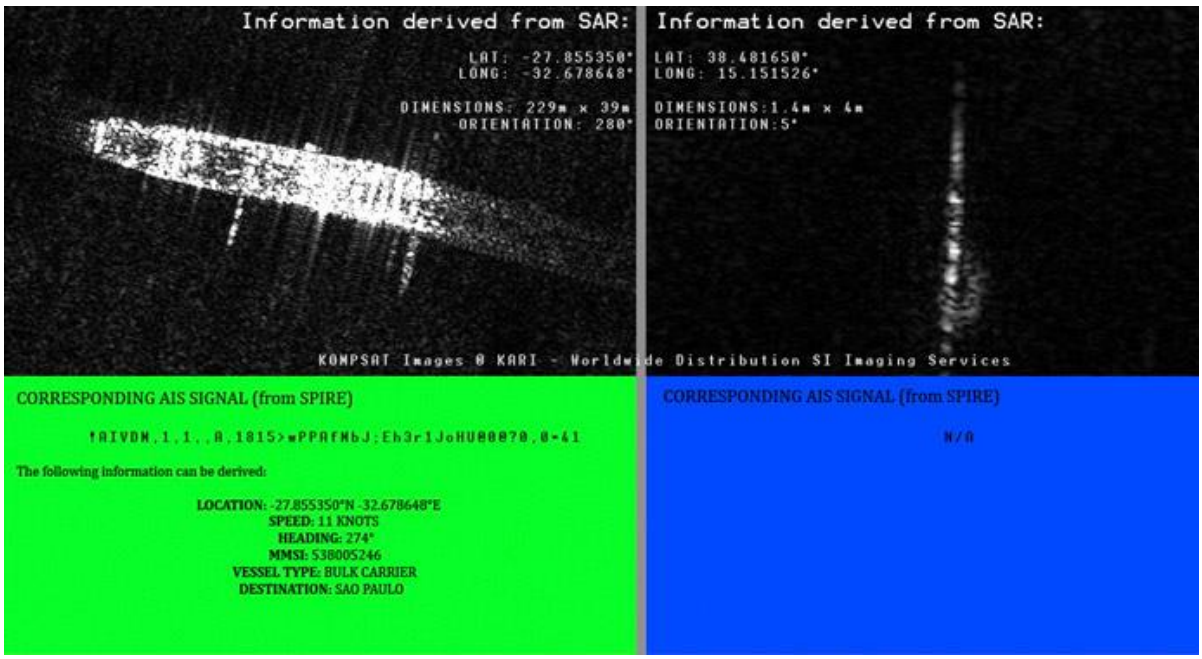
growing countries in the environmental monitoring market as a whole between 2016 and 2021, due to their increasing industrialisation. **The use of SAR to detect certain types of pollutant has been proven** and as space capabilities to monitor issues such oil spill, salinity and turbidity increase, their ability to complement, guide or replace existing monitoring techniques will grow.

Detailed knowledge of the sea floor is critical for understanding how the earth's systems interact and to support coastal zone management, environmental protection, tsunami modelling, inundation forecasting, and charting. **The hydrographic survey equipment market is expected to grow to £3.62 billion by 2021**, at a CAGR of 5.43% during the period. The rise in maritime commerce, increase in demand for accurate nautical charts, and coastal zone management and development is expected to drive this growth.

A growing global middle class will drive growth in the leisure marine market, with Brazil, Russia, India, China, Turkey, Slovenia, Greece, Australia, New Zealand, the Middle East and Scandinavia all identified as future growth markets in the UK Marine Export Strategy 2013. This may result in **a potential end-user market for maritime data** similar to that used by commercial vessels for situation awareness, vessel security and tracking, but **the market is at a very early stage of maturity**.

The growing market for marine autonomy will have a symbiotic relationship with space. Autonomous vehicles can play a part in most of the identified markets, as they can be deployed for activities related to scientific research, hydrography and bathymetry, maritime border and security and fisheries control (including anti-IUU missions).

The aquaculture and fisheries and maritime border and security markets warrant the greatest additional exploration, followed by the marine environmental observation, hydrography and bathymetry and marine leisure markets.



2. The brief

In 2015, U.S. Coast Guard Rear Admiral Brian Salerno said: "We cannot hold polluters accountable unless we can match them to their spills; we cannot keep vessels from colliding if we don't know where they are; we can't rescue survivors unless we find them; and we cannot intercept those who would do us harm if they are able to blend in with the millions of recreational boaters who lawfully enjoy our ports and coastal waters." (*Five Maritime Security Developments That Will Resonate For A Generation*, Harvard National Security Journal).

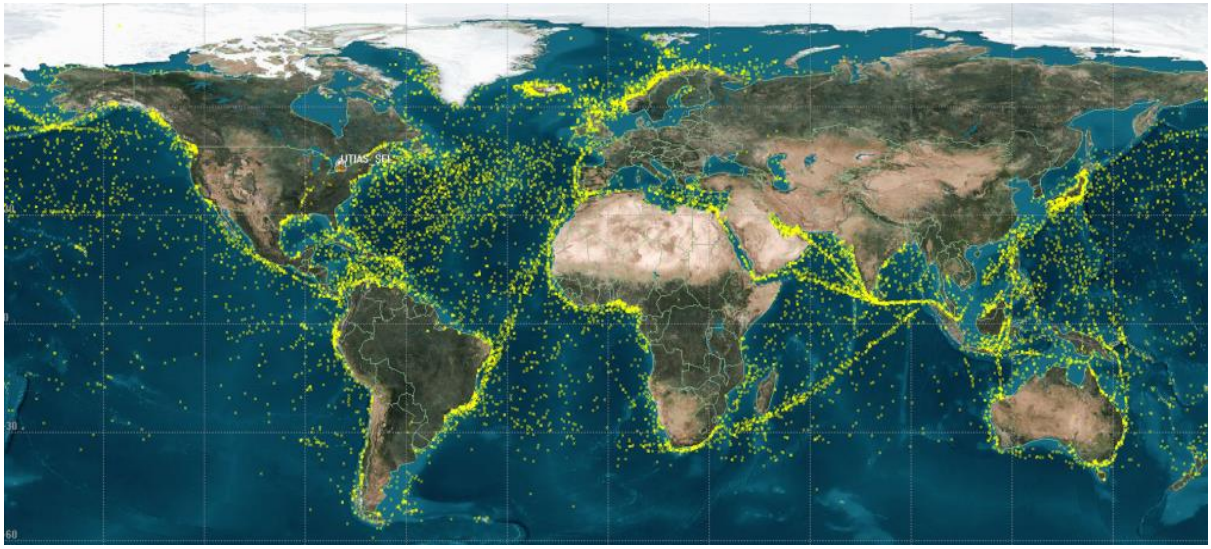
To that list can be added challenges related to tracking climate change, countering illegal fishing, sea floor mapping and many more tasks related to the burgeoning Blue Economy.

The key objective of the study is to identify opportunities for the UK Space sector to add value to the stakeholder organisations and businesses involved in and impacted by issues and user needs surrounding Maritime Surveillance.

Fuelled by the commercialisation of satellite data, services and infrastructure, the UK space sector aims to build a £40bn UK industry by 2030, with the creation of 100,000 new jobs. The goal is to increase upstream revenues from £1bn to £3bn and fast-track downstream revenues from £8bn to £37bn over the next 15 years. Through the Space Innovation and Growth Strategy (IGS), a collaboration between Government, business and academia, the space sector has set a vision and blueprint for growth. The IGS Growth Action Plan 2014 – 2030 identifies 15 future high-growth markets, including maritime surveillance.

This is set against the background of the overall Space Innovation and Growth Strategy (IGS), which was conceived in 2010 to create a partnership between industry, government and academia to develop, grow and exploit new space related opportunities.
The Case for Space 2015 report shows that the UK space industry is already worth £11.8 billion and has been growing by an average of 8.6% year-on-year since 2010. The IGS' target is for a 10% share of the global space market, which is estimated to be £400 billion by 2030.

The growth of the Blue Economy means that Maritime Surveillance – and the ongoing need for technological developments – has the potential to play a major part in the achievement of the 2030 target.



3. Market definition and sectors

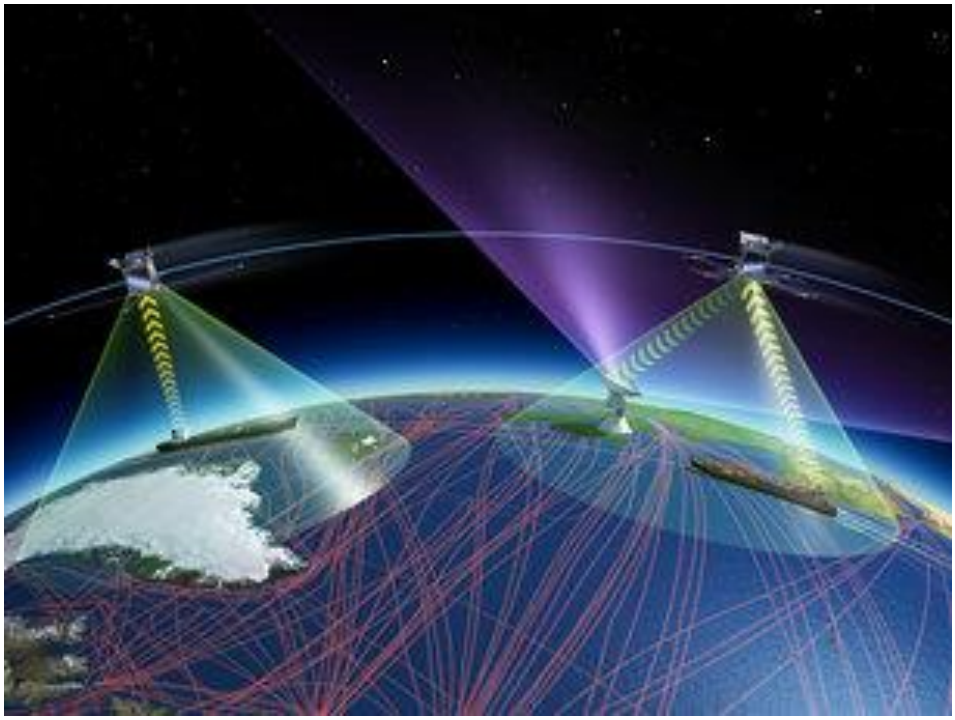
According to the EU, Maritime Surveillance is "the effective understanding of all activities carried out at sea that could impact the security, safety, economy, or environment of the European Union and its Member States." The aim of Maritime Surveillance is to understand, prevent (where applicable) and manage the actions and events that can have an impact on all related activities and sectors.

For the purposes of this report, "Maritime Surveillance" focuses primarily on the satellite-based monitoring of all maritime operations and the satellite-based monitoring of the condition and health of the marine environment.

While the primary aim of the report is to inform UK businesses of potential opportunities arising in this marketplace, the global nature of the oceans – they cover 71% of the Earth's surface, 99% of the living space on the planet and 90% of global trade is moved across the oceans – means that it embraces the total worldwide market.

We have identified and explored five distinct market areas, which are:

1. Fisheries and aquaculture
2. Maritime border and security
3. Marine environmental observation
4. Hydrography and bathymetry
5. Marine leisure



4. Market context

The traditional view of the scope of the maritime industry, taking in such sectors as shipping and fishing, has been overtaken by the advent in recent years of the Blue Economy. Definitions of the Blue Economy vary widely. WWF have typically focused on the sustainable elements, but they recognise that for others, it simply refers to any economic activity in the maritime sector, whether sustainable or not. The term therefore combines the traditional maritime sectors of shipping, fishing and oil and gas with the newer industries such as aquaculture, renewable energy, biotechnology and coastal tourism.

Taking aquaculture as an example of the new industries, it will be vital in feeding the growing world population - which according to the UN will rise from 7.3 billion in 2015 to 8.5 billion by 2030, 9.7 billion in 2050 and 11.2 billion in 2100. Future growth in fish production and consumption is expected to come from aquaculture, which is an efficient protein production method (in comparison to terrestrial livestock farming), and can produce traceable, high quality, healthy seafood in large volumes.

In 2015, WWF assessed the value of key ocean assets at over US$24 trillion, with two-thirds of that based on assets that require healthy, productive oceans. In fact, based on gross marine product, the ocean may be considered the world's seventh largest economy. According to the European Commission, the Blue Economy contributes just under €500bn per year to the European economy, supporting 5.4 million jobs.

As will be discussed in the following sections of the report, this Blue Economy provides growing opportunities for satellite technologies in services and solutions that enable sustainable growth within the maritime environment, also known as 'Blue Growth'.

The essential components for delivering Blue Growth can be viewed as:

- Marine knowledge to improve access to information about the sea.
- Maritime spatial planning to ensure an efficient and sustainable management of activities at sea.
- Integrated maritime surveillance to give authorities a better picture of what is happening at sea.

For each of these components, satellite positioning, navigation, Earth Observation and communications are key enabling technologies. Innovation in downstream services for the Blue Economy will undoubtedly be in the form of hybrid solutions, drawing on the breadth of satellite capabilities and data.

Particularly important is the requirement for resilient, ubiquitous, high-quality connectivity for large volumes of data – a maritime cloud. Whilst continuing to support EU initiatives, the UK has the potential to be a leading actor in this field, with the ability to draw on a multitude of skills.

The UK benefits from a number of active maritime clusters (as identified in the recent study, Blue Growth: Opportunities for marine and maritime sustainable growth), a successful offshore energy industry and numerous world-leading oceanographic research institutes.

4.1. Global trade

The world's economy trades by sea. Around 80% of global trade by volume, and over 70% by value, is carried by ships and handled by ports worldwide. The United Nations Conference on Trade and Development (UNCTAD) estimates that the operation of merchant ships contributes about US$380 billion in freight rates within the global economy, equivalent to about 5% of total world trade. There are over 50,000 merchant ships trading internationally, transporting every kind of cargo. The world fleet is registered in over 150 nations, and manned by over a million seafarers.

The world's commercial fleet has grown rapidly in the past quarter of a century. At the start of 2017 the global fleet totalled 1.86 billion dwt compared to 621 million dwt at the start of 1992, exhibiting a growth multiple of three over the period. Predicted increases in world seaborne trade can be seen in Figure 1, aligned to predicted DGP and population rises.

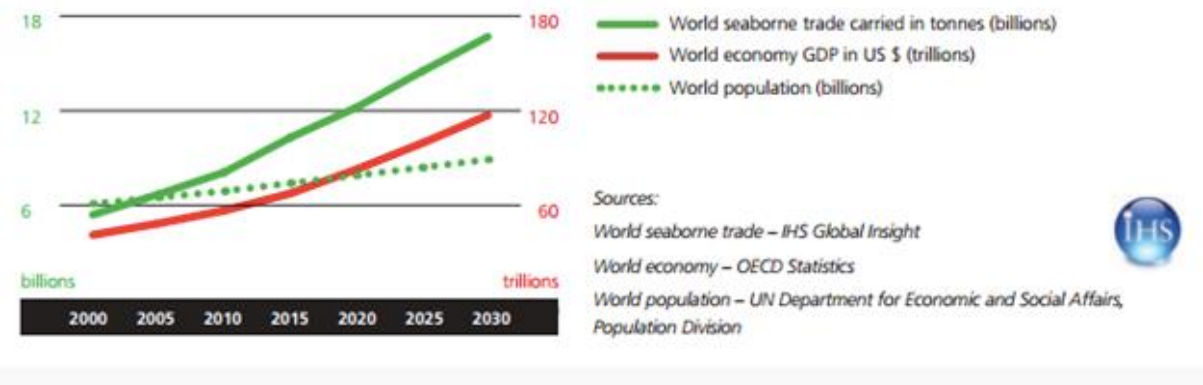


Figure 1: Predicted increases in world seaborne trade, GDP and population
Source: International Chamber of Shipping

4.2. Regional comparisons

As Figure 2 highlights, world seaborne trade (by tonnage) is dominated by Asia, with the Americas and Europe vying for second place in the global league table.

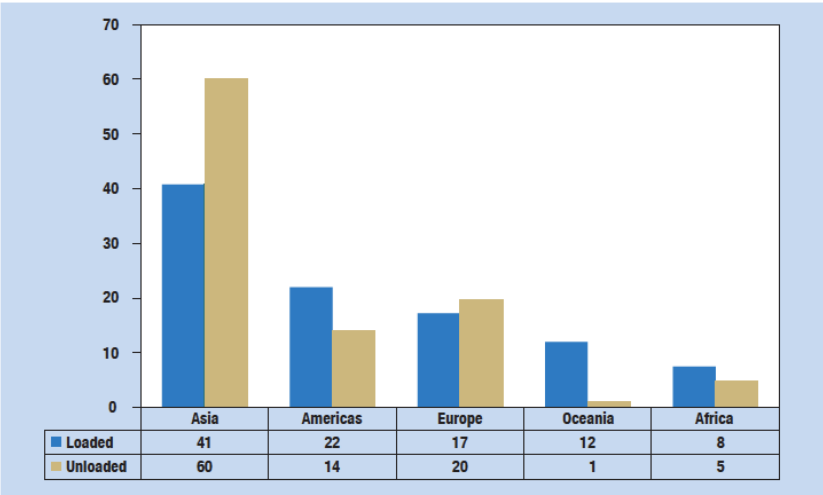


Figure 2: World seaborne trade by region, 2015 (Percentage share of world tonnage)
Source: UNCTAD Review of Maritime Transport 2016

Asian ports also dominate league tables for vessel port calls, capturing 45% of the global total (as Figure 3 illustrates), followed by Europe at 35% and a significant drop to North America at 5%.

Vessels	Africa	Asia	Caribbean	Europe	North America	Oceania	South America	Grand total
Cargo-carrying ships								
Bulk carriers	9 486	69 150	3 684	17 048	10 553	14 051	13 403	137 375
Container ships	20 418	180 705	16 729	64 900	14 620	7 188	17 669	322 229
Dry cargo/passenger ships	36 915	375 134	13 035	431 849	48 834	40 651	19 780	966 198
Tankers	9 160	127 312	6 599	62 721	10 387	3 306	10 312	229 797
Grand total	75 979	752 301	40 047	576 518	84 394	65 196	61 164	1 655 599

Figure 3: Vessel port calls by region and type, 2015
Source: UNCTAD Review of Maritime Transport 2016

Developed countries own 60% of seagoing merchant vessels, with developing countries in Asia claiming 36%, as shown in Figure 4:

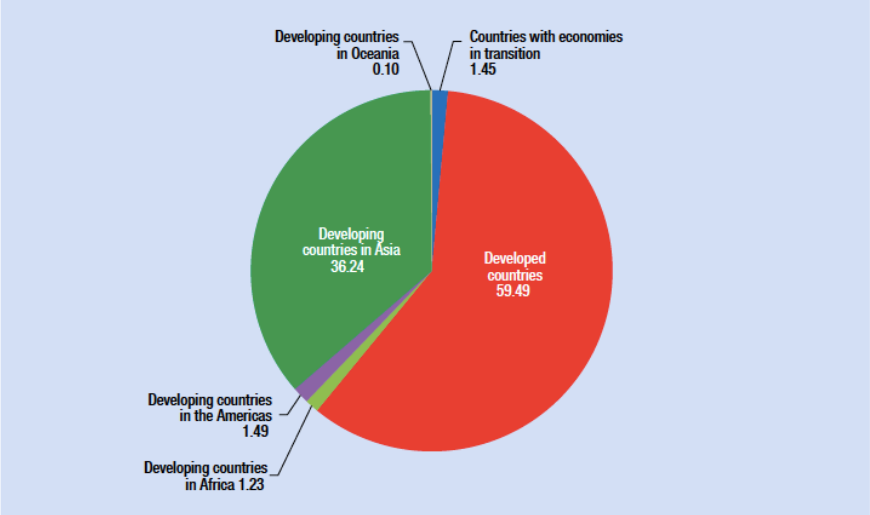


Figure 4: Share of vessel ownership by country grouping, 2016 (Percentage)
Note: Propelled seagoing merchant vessels of 1,000 gross tons and above, as at 1 January
Source: UNCTAD Review of Maritime Transport 2016

The pivot point of maritime trade is expected to shift from West to East in the coming years, driven by China's rapid economic expansion. The next 15 years will see South East Asian nations, Indian sub-continent and emerging economies of South America drive business growth.

4.3. Recent challenges

International shipping companies have been confronted by the challenges of the global recession, compounded by oversupply of vessels ordered during years of commercial comfort and further exacerbated by long lead times for vessel build and disposal.

The shipping market reaction to the recession has demonstrated its flexibility and adaptability. Taking advantage of corresponding low fuel costs, low vessel values and oversupply, the industry has adopted low speed steaming and floating storage as effective mechanisms to address the short to mid-term market conditions. Alliances and take overs are underway.

The oil and gas industry has suffered from lower prices with forecasts indicating a significant impact being the decommissioning of a number of off shore installations. Many regulatory obligations mean oil companies are liable for the impact of installations in perpetuity. This presents opportunity for low-cost space-enabled maritime surveillance solutions.

5. Market review

5.1. Size and value

The UK maritime sector is worth £11bn to the economy and employs 100,000 people. However, the key maritime sector reports do not explore the value of maritime surveillance, as defined here, although the Case for Space report suggests UK navigation capabilities are worth just over £1bn.

5.2. Global Navigation Satellite Systems

The most detailed analysis on device value is provided by the European GNSS Agency (GSA). It estimates the global core revenues of all GNSS devices at around €230bn, with maritime accounting for 1.1% of a market dominated by location based services (53.2%). By 2023, the GSA expects total GNSS device revenue to reach just under €300bn.

Within the maritime GNSS component and receiver manufacturer market, Asian companies continue to dominate. European firms have a 28% market share. The top three manufacturers are French-owned Orolia (including McMurdo), Hexagon (Sweden) and Laird (UK). Among system integrators, European companies have 45% market share compared to North America's 35% share. The top three companies are Kongsberg (Norway), Navico (Norway) and Safran (France).

The GSA suggests that recreational vessels account for an increasingly larger share of GNSS shipments, and will continue to drive growth in this sector. Around 1.1 million devices were shipped in 2015, compared to around 550,000 in 2006.

In the Search and Rescue category, the GNSS highlights that the shipment of Cospas-Sarsat10 GNSS-enabled emergency beacons stabilised at around 80,000 units (648,000 EPIRBs and 580,00 PLBs) but adds that AIS-SART beacons have increased in popularity following the rescue of Andrew Taylor from the Clipper Round The World Yacht Race.

5.3. Satellite Earth Observation

A report from Northern Sky Research suggests that the market for data, value-added services and information products from satellite based Earth Observation will grow to $5.1bn by 2023. Up from $2.1bn in 2013.

There are no figures for the value or volume of Earth Observation data deployed by the maritime sector. However, the workshop suggested that it was at a very low level, due to cost, resolution and frequency, with usage mainly task-based, using SAR for security (piracy, anti-smuggling and border control operations) and search and rescue applications.

5.4. Technology

An Organisation for Economic Co-operation and Development (OECD) report, the Space Economy at a Glance12, suggests that, as of spring 2014, there were six regional and global navigation satellite constellations under development, with the American Global Positioning System (GPS) already fully operational and free at the point of use.

The OECD predicts that: "around 100 navigation satellites could be in orbit by 2020, with at least four different satellite navigation systems with global coverage (GPS, Galileo, GLONASS and Beidou) transmitting signals on multiple frequencies".

Ahead of Galileo being fully operational, the European Commission has developed the European Geostationary Navigation Overlay Service (EGNOS), a satellite-based augmentation system that increases the accuracy of GPS positioning and provides information on its reliability in Europe.

5.5. Customer Base

The market for new ship building has reduced significantly in the past few years. Clarksons Research reported that only 113 yards took orders (for vessels 1,000+ GT) in 2016, compared to 345 in 2013, with tanker orders down 83% and bulkers down 46%. There was little ordering in any sector, except Cruise (a record 2.5m GT and $15.6bn), Ferry and Ro-Ro. The value chain for maritime device sales can be seen in Figure 5.

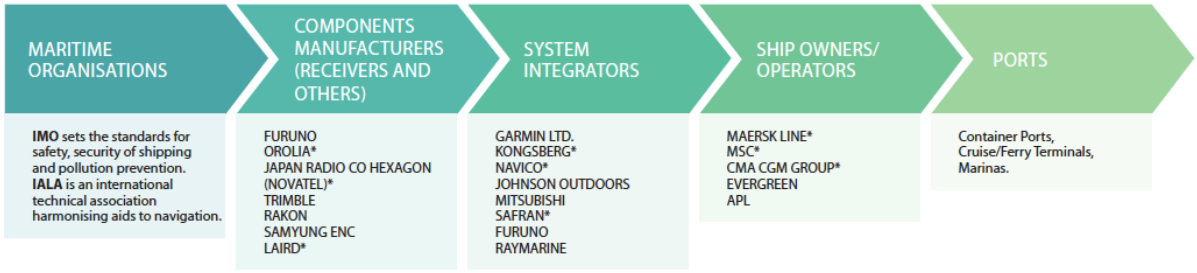


Figure 5: Maritime Value Chain
Source: GNSS Maritime Market report, Issue 4, 2015

UK international trade in the maritime leisure market is valued at £938m (32% of total market revenue) and trading is predominantly with Eurozone partners (£428m), North America (£119m) and Asia £93mn (excluding China).

According to the UK Marine Export Strategy (published by the UKTI and UK Marine Industries Alliance in 2012), the major European markets of France, Italy, Germany, the Netherlands and Spain remain key for leisure boat sales and equipment. However, over the next five to 10 years, growth in the leisure marine market will be driven by Brazil, Russia, India, China, Turkey, Slovenia, Greece, Australia, New Zealand, the Middle East and Scandinavia.

5.6. Unmanned surface vessels

The growing market for marine autonomy will have a symbiotic relationship with space, so development of this cross-cutting capability is worth monitoring, over and above the specific market segments outlined below. Autonomous vehicles can play a part in most of the identified markets, as they can be deployed for activities related to scientific research, hydrography and bathymetry, maritime border and security and fisheries control (including anti-IUU missions).

The unmanned surface vessels market is expected to grow to $861.37 Million by 2021, at a CAGR of 14.51%, driven by the rising demand for maritime security, protection of shallow waters and ports, and the need for ocean data and mapping, globally.

5.7. Mid-term market drivers

The world in 2030 will be shaped by powerful global trends. Population growth and increasing urbanisation will lead to increasing difficulties in providing adequate amounts and quality of food and water and increasing expectations with regard to health, safety, security and environmental impact. Significant economic trends are the increasing GDP share of developing countries; a continued growth of energy consumption, and a growing volume of trade with changing patterns. The two possibly biggest drivers are climate disruption and digitalisation. Both are accelerating and their impact might be larger than currently expected. The maritime sector will be affected by these trends significantly, and these headlines have been categorised by the Community of European Shipyards (Global Trends Driving Maritime Innovation, CESA, 2016) as:

Extreme weather due to climate change will give rise to: Increased requirement for robustness of ships, ports and offshore structures for more severe weather conditions Increased use of weather routing Utilisation of arctic routes (Northwest, Northeast) Exploitation of arctic fossil fuel reserves Enforcement of coastal infrastructure (dikes, ship fairways)	**ICT developments will lead to:** Higher degree of automation, automation of systems, autonomous operation Sea-based and shore-based operation: integration and transformation Need for secure connectivity against cyber attacks Electronic data instead of legal paper documentation Digitalisation will lead to data access issues, IPR, etc.	**Energy demand and supply will require:** In Europe, large increase in renewable energy Reduction in oil prices leading to decommissioning of established off shore oil infrastructure Significant increase in production and transport of clean fuels (LNG, shale gas, hydrogen) Exploration of reserves in deeper water, and harsher environments Port infrastructure for offloading
Food and water supply challenges will give rise to: Transport of fresh water and food Food production at sea (fish farming, aqua farming) Installation of desalination plants Need for specialised infrastructure	**Reduction of environmental impact will demand:** Stricter environmental regulations for shipping to reduce emissions to air and sea Stricter regulations for offshore activities, including renewable energy Stricter emission control in ports	**Waterborne trade growth will drive:** Increase in throughput of ports Port congestion, increasing ship size will lead to port extensions Alternative fuel trade / transport of LNG, methanol or hydrogen Bunkering of alternative fuels
Population growth will lead to: Increasing urbanisation / new and upgraded port infrastructure Increased Waterborne transport in general Increased use of ferries, cruise ship and leisure craft in particular	**Economic growth will lead to:** Increased transport of goods, energy, raw materials Increased transport of fresh water Harvesting raw materials offshore Significant investment in new port facilities	**Health, safety and security expectations will affect:** Crew working conditions, and seafarer safety Stricter safety and security standards

To face such challenges and opportunities in the coming years, maritime stakeholders need to maintain a competitive edge in the market and are on the lookout for innovative ways to achieve this. The potential for innovation appears to be deepening (as evidenced in greater emphasis on such areas as Digital Ship), and maritime surveillance capabilities can play a broad and supporting role across the piece.

6. Market opportunities

6.1. Headline opportunities

Market	Potential users	User need	Market size	Market overview	Potential space opportunities	Potential challenges
Fisheries and aquaculture	State / international agencies. Commercial entities NGOs.	To guard against IUU. To assist with the development of aquaculture.	The aquaculture market = $202.96 Billion By 2020. IUU costs the global economy $23.5 billion every year.	1 in 5 fish landed is caught illegally. Population growth demands aquaculture.	AIS tracking. Satellite data to aid site selection for aquaculture.	AIS can be turned off. Low quantity of EO satellites with SAR capability. Expensive.
Maritime border and security	State / international enforcement agencies. Regulators. Shipping. Oil & gas. NGOs. Insurers.	To protect and preserve human life and physical and intellectual assets from dangers. To deter, prevent, detect and/or prosecute customs and border breaches.	The global maritime border and security market is estimated to grow to $23.67 Billion by 2021.	Maritime security services enable risk assessment and investigation. Border vulnerabilities are exploited by criminals /criminal organisations.	Earth Observation. Connectivity to other data-gathering assets. GPS positioning for 'overboard' incidents. Earth Observation.	EO image capture need to coincide with incidents. Resolution issues re hard evidence.
Marine environmental observation	Regulators. Shipping. Oil & gas. Academia. NGOs. Insurers.	To identify changes and long term impacts in the marine environment.	The global market for water quality sensing and monitoring equipment = $6.49 billion by 2019.	MEO attempts to monitor changes (especially harmful ones) in the marine environment.	SAR to detect pollutants. Potential to monitor oil spill, salinity and turbidity. Connectivity of Autonomous monitoring	Cost of data analysis. Speed of data delivery. Level of data granularity available.
Hydrography and bathymetry	State / international agencies. Commercial entities NGOs.	Detailed knowledge of the sea floor and the water column (less than 2% of the sea bed is mapped accurately)	The hydrographic survey equipment market = £3.62 billion by 2021	The world's oceans are poorly mapped and the ocean bed changes constantly.	Improvement in space based bathymetry using SAR and LiDAR.	Limited to shallow waters. Subject to inaccuracies due to distance.
Marine leisure	Commercial leisure companies. Individual leisure seafarers.	Position and navigation. planning tools (tide planners, wind finders). Vessel tracking. Personal safety.	The UK leisure, superyacht and small commercial marine industry = £3.01bn in 2016.	A growing global middle class will drive growth in the leisure marine market.	Navigation. Personal safety.	Complex and fragmented market only just being addressed by larger players.

Over subsequent pages, each of these is presented and explored in more detail.

6.2. Fisheries and aquaculture	
Potential users	• State and related international agencies (e.g. controllers of Economic Action Zones and Marine Protection Areas). Commercial entities (offshore wind and wreck salvage companies). Academia. NGOs.
User need	• To help guard against – and lead prosecutions related to – Illegal, Unreported and Unregulated fishing (IUU) and assist with the planned growth of aquaculture.
Indicators of market size / potential growth	• The aquaculture market is expected to be worth $202.96 Billion by 2020 (Grand View Research, 2015). China was largest market for aquaculture in 2013, accounting for about 53% of global market share ($77,934.8 million). Rapid growth will be due to favourable climatic conditions for aqua farming, availability of resources and labour. • Asia Pacific (excluding China) was the second largest market for aquaculture in 2013, with market demand of 17.965.2 kilo tons, and is estimated to grow with a CAGR of 2.1% to 2020 due to ideal climatic conditions and technological innovation. • Estimates for IUU range from 11 to 26 million tonnes per annum – equal to 14 or 33% respectively of the world's total legal catch (fish and other marine fauna), with an estimated value of $10Bn - $24Bn. • The situation off the coast of West Africa is particularly critical, where IUU fishing accounts for an estimated 40% of fish caught – the highest level worldwide.
Market overview	• Roughly one in every five fish landed around the world is caught illegally. Nearly 3% of the world's oceans are now classified as Marine Protection Areas, and having developed such policies, the challenge shifts to devising cost effective ways to enforce them. • Management, effective real-time situational awareness and enforcement are essential for the preservation of the resources in these water spaces and especially the hundreds of fish species that they support. In many areas of the world it is acknowledged that many illegal fishers go about their work with virtually no fear of being caught. • Aquaculture includes farming of aquatic organisms such as molluscs, fish, crustaceans and other aquatic flora and fauna. Increasing consumer awareness of health benefits associated with seafood and growing consumption serves as a key driver for development of the market. In addition, the market demand is expected to be further fuelled by the lack of naturally available varieties owing to extensive fishing.
Potential space opportunities	• Satellites can support counter-IUU activities in a variety of ways: AIS tracking can identify suspect vessels and patterns of movement; satellite-enabled comms can help rapid transfer of intelligence and to cue and control unmanned assets working in stealth mode in 'honeypot' IUU areas. • Satellite data can be used in the aquaculture industry for thermal and current imaging in assisting in site selection for fish farms and shell fish farms. As fish farms are often in remote environments, satellites can be used in communications, remote sensing and data networks as well as exploring aquaculture interaction with the environment and animal tracking. It can give measurements of greenhouse gases in soil and oceans and give indications of ecosystems for the best shellfish production. • SAR has been demonstrated to identify ships of around 9m length and greater so could be explored as a system for monitoring vessels whether AIS is on or not. This allows for another layer of situational awareness to be added to high risk zones for illegal fishing and other maritime criminal activity.
Potential challenges	• AIS is very helpful but it tends to be used only by the legal operators; tracking the rest can present challenges. • The relatively low quantity of EO satellites with SAR capability means that image capture windows don't always coincide with target incidents. • The high-power usage of SAR means image capture is relatively expensive.

6.3. Maritime border and security	
Potential users	• State and international enforcement agencies (e.g. national coast guards, port authorities, border forces, Interpol, etc). Commercial entities (e.g. security companies) and regulatory bodies (e.g. EMSA, the European Maritime Safety Agency). Commercial bodies (e.g. shipping, oil and gas companies, security companies). Insurers. NGOs.
User need	• To protect and preserve human life and physical and intellectual assets from dangers associated with illegal and unethical acts, threats and accidents, thus ensuring the safe passage of all waterborne assets and reassurance and comfort for crew and passengers. • To respond rapidly to major arising incidents (e.g. natural disasters, search and rescue). • To deter, prevent, detect and/or prosecute breaches of customs and border regulations (e.g. illegal immigration, human trafficking, and illegal transportation of contraband).
Indicators of market size / potential growth	• The global maritime border and security market is estimated to grow from $16.71 billion in 2016 to $23.67 billion by 2021, at a CAGR of 7.2%, driven by increasing incidents of piracy and marine terrorism on vessels, ports, and other critical infrastructure. • The surveillance and tracking technology segment is expected to have the largest market share and dominate the maritime safety market from 2016 to 2021. • The cost of protecting maritime assets was $34.2bn in 2013: the insurance premium volume of all countries covered under the International Union of Marine Insurance. • The risk assessment and incident investigation service segment is expected to grow with the highest CAGR from 2016 to 2021, as it provides an in-depth assessment of existing security arrangements and finds out the threats and vulnerabilities onboard or onshore. • North America is expected to dominate the market to 2021, due to a developed commercial maritime industry that contributes highly to the national economy. APAC also offers extensive growth avenues, mainly due to extensive expansion of regional port capacities and development of maritime security regimes, particularly in countries such as India, China, and Singapore.
Market overview	• Maritime border and security services enable risk assessment, investigation and training of people involved in maritime security. The maritime security service market is driven by factors such as ungoverned marine regions, increased awareness about maritime security, and use of advanced technologies and solutions. • Customs agencies enforce a state or nation's tariff and tax collection as goods, livestock, transport, products, hazards and people transit in or out of that state or nation. • Emerging currently are advanced motion and intrusion detection technologies along with Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) detectors, Hazardous Materials (HAZMAT) detectors, and laser range finders. • EMSA offers integrated services to all EU and EFTA Member States, which allows full use of the integrated vessel reporting information (terrestrial and satellite) and national vessel position data such as coastal radar, patrol assets, and leisure craft. The service now includes meteorological and oceanographic data, as well as automated behaviour algorithms, configurable to provide alerts responding to user-defined policies.
Potential space opportunities	• Earth Observation – potential applications for space-based assets in search and surveillance activities over a wide area. Augmenting existing terrestrial situational awareness capabilities. • Connectivity – the opportunity to relay more data about an incident to more people in close to real time could improve risk factors significantly. • Position – GPS positioning of incidents and those stranded or 'overboard'.
Potential challenges	• EO needs image capture opportunities to coincide with a given incident or occurrence. • Active EO (such as SAR) and passive EO (optical) are both limited when acquiring evidence-quality data, as the higher the resolution the smaller the swath/coverage area.

6.4. Marine environmental observation	
Potential users	• State and international regulators (e.g. Port Authorities, the European Maritime Safety Agency, etc). Commercial entities (e.g. shipping, oil and gas and offshore wind companies). Academia. NGOs. Insurers. Financiers.
User need	• To identify changes in the marine environment (biodiversity, oil spill and other pollution, algal bloom, climate change-related trends, changes in coastal zones, etc).
Indicators of market size / potential growth	• The global environmental sensing and monitoring market is expected to reach an overall value of $19.56 billion by 2019, growing at a CAGR of 6.7% (Source: Technavio, 2015). • Plans for large scale decommissioning of UK off shore oil between 2015 and 2050 are estimated to cost £30Bn-£60Bn (source: FT big read North Sea oil: The £30bn break-up) • Within that, the global market for water quality sensing and monitoring equipment is expected to reach $6.49 billion by 2019, growing at a CAGR of 7.2% thanks to advancements in aquatic sensors such as salinity, turbidity, and flow sensors. • China and India are estimated to be the fastest-growing countries in the environmental monitoring market as a whole between 2016 and 2021 (Source: Markets and Markets, January 2017), due to their increasing industrialisation.
Market overview	• As populations grow, industrial development increases and agricultural requirements skyrocket. But unsustainable practices across industries have resulted in rapid degradation of air, soil and water quality levels worldwide, which has in turn led to a rise in demand for devices that can help detect changes in the environment. • This is where Environmental sensing and monitoring systems come in. These systems consist of satellites, portable ground and remote sensors, and measurement and model data. • A wide range of regulations attempt to govern maritime activity that has potentially harmful environmental effects (e.g. MARPOL Annex I: prevention of pollution by oil & oily water), but enforcement remains the key challenge, and awareness. Contravention of MARPOL, for example, can be hard to detect at source.
Potential space opportunities	• The use of SAR to detect certain types of pollutant has been proven. • As space capabilities to monitor issues such oil spill, salinity and turbidity increase, their ability to complement, guide or replace existing monitoring techniques will grow. • The use of space connectivity to allow real-time / near real-time monitoring of decommissioned off shore installations via unmanned and or autonomous systems.
Potential challenges	• Specifically when considering the use of SAR in the detection of oil on the ocean surface, growth challenges include the cost of data analysis and the access to SAR imagery close to real time. It is also necessary to ensure a satellite pass coinciding with an incident or geo-temporal reference of interest. • Additionally, a broader challenge includes the ability to provide a level of data granularity that allows decisions to be made / to properly complement other local marine environmental data gathering techniques. • Furthermore, the issue of time lag from data capture through analysis and to actionable information arriving with an operator/decision maker is an important consideration with closest to real time being most desirable.

6.5. Hydrography and bathymetry	
Potential users	• State and related international agencies (e.g. national hydrography offices, the IHO, port authorities). Commercial entities (e.g. oil and gas, offshore wind, shipping and wreck salvage companies). Academia. NGOs.
User need	• Detailed knowledge of the sea floor is critical for understanding how the earth's systems interact and to support coastal zone management, environmental protection, tsunami modelling, inundation forecasting, and charting [IHO Data Centre for Digital Bathymetry].
Indicators of market size / potential growth	• The hydrographic survey equipment market is expected to grow to £3.62 billion by 2021, at a CAGR of 5.43% during the period (Source: Markets and Markets, July 2016). The rise in maritime commerce, increase in demand for accurate nautical charts, and coastal zone management and development is expected to drive this growth. • The largest market areas are considered to be: offshore oil and gas (for the planning, installation and ongoing inspection and maintenance of offshore production platforms and pipelines); hydrographic survey (producing navigational and other charts for safe vessel transit and seafloor exploration activities); mapping commercial ports and harbours, especially the 2,000 largest in the world; the definition of Exclusive Economic Zones (to establish nations' rights over seabed 'real estate' and the associated oil, gas and mineral rights); and the identification and assessment of locations suitable for offshore wind farms.
Market overview	• The world's oceans are poorly mapped. 71% of Earth's surface is covered with water, yet only about 10% of the seafloor has been surveyed by modern echo sounders [IHO]. Many navigational charts are based on information that is over 100 years old. • The ocean bed is constantly changing, influenced by tectonic shifts, seismic activity, marine bio diversity and weather and currents such that many charts have inadequate or sparse information, and there is a real thirst for as much new data as possible. • GEBCO (the General Bathymetric Chart of the Oceans) has set an ambitious goal of comprehensively mapping the entire ocean floor by 2030 (Seafloor 2030).
Potential space opportunities	• Improvement in space-based bathymetry using SAR. • Improvement in space-based bathymetry using LiDAR. • Enabling Marine Autonomy through command and control connection with unmanned vessels.
Potential challenges	• Space -bathymetry is limited to applications in shallow waters (depth less than 10m). The data is generated through analysis of backscatter from surface water and then interpreted to determine the underlying bathymetry. It is not an application suitable for • Space-based LiDAR is subject to inaccuracies caused by the distance between the sensor and the target as limitations created by the light being blocked by moisture/dust/clouds in the atmosphere.

6.6. Marine leisure	
Potential users	• Commercial leisure companies (cruise ships, boat manufacturer and boat hire companies). Individual leisure seafarers.
User need	• A cross-cutting range of needs includes position and navigation devices, planning tools (tide planners, wind finders), comms capabilities, vessel tracking and personal safety (e.g. man-over-board products).
Indicators of market size / potential growth	• The pleasure cruise sector is a vibrant and growing market. 15 more new cruise ships will add 39,637 or 8.1% to passenger capacity by the end of 2017 – generating $3.6 billion more in annual revenue for the cruise industry. By 2019, 25.3 million cruise passengers are expected to be carried worldwide of which 55.8% will originate from North America, 25.1% Europe and 19.1% the rest of the world. • Worldwide sourcing of cruise passengers in 2015 was 58.6% North America (Canada, United States and Mexico) followed by Europe (25.9%), Asia (8.5%) and Australia (4.3%). • A growing global middle class will drive growth in the leisure marine market, with Brazil, Russia, India, China, Turkey, Slovenia, Greece, Australia, New Zealand, the Middle East and Scandinavia all identified as future growth markets in the UK Marine Export Strategy 2013.
Market overview	• A growing global middle class is driving growth in the marine leisure sector, resulting in a potential end-user market for maritime data similar to that used by commercial vessels for situation awareness, vessel security and tracking. • The UK leisure, superyacht and small commercial marine industry is vibrant, with revenues growing in 2015-16 by 1.6%, to £3.01bn (the last time the industry posted revenues of over £3bn was 2008/9). Key with key export markets include: Eurozone £392m (44.6%); North America £157m (17.8%); Other European Countries (including Russia) £90m (10.2%); China £40m (4.5%); Middle East £30m (3.4%). • The European leisure boating industry is valued at £20 billion (European Boating Industry), and is dominated by small and medium businesses. • In 2014, Inmarsat estimated the marine leisure addressable market as consisting of 233,000 boats. 2015 was the first time that they had made specific products (Fleet One – a comms offer) available to small vessels market (leisure and fishing).
Potential space opportunities	• The UK already has renowned manufacturing and integration capability through companies such as RayMarine, L-3 Marine, Marine Data Systems and SRT Marine Technology. • UK-based Inmarsat is a world leader in global mobile satellite communications and the leading satellite supplier to the maritime market. • Providing support for navigation and safety devices look promising.
Potential challenges	• The market is complex and dominated by Small and Medium Enterprises, so routes to market may be fragmented. • Established players such as Inmarsat mark the leisure marine market as being very much in the 'early days'. • Market offers for connectivity, voice and video may be more appealing to customers in the early days than for surveillance products.

7. Recommendations

Advances in marine technology will create pull for connectivity and the early signs of this are being seen in surveillance applications that cover a number of the sub markets in this report. Autonomy lends its self to border control, security (of offshore assets and of EEZs), hydrography and bathymetry.

Space is a key enabler in the maritime domain and specifically in surveillance. Connectivity – allowing command and control of autonomous surface and subsurface vessels – is a market that shows promise.

Two markets of notable promise are aquaculture and fisheries and maritime border and security. These are explored further below.

7.1. Aquaculture and fisheries

Of all studied markets, the aquaculture and fisheries market is predicted to achieve the most significant growth in the coming years. Aquaculture is the most rapidly expanding food industry in the world, as a result of declining wild fisheries stocks and profitable business.

The market is expected to grow to $202.96 Billion By 2020 (from a reported $135.10 billion in 2012). In 2008, aquaculture provided 45.7% of the fish produced globally for human consumption; increasing at a mean rate of 6.6% a year since 1970.

While much aquaculture development takes place in fresh water as well as in coastal waters, there is a growing trend to further offshore activity to lessen the impacts of inshore aquaculture (e.g. farm waste, chemicals, parasites). In 2016, for example, NOAA Fisheries announced that federal waters in the Gulf of Mexico – stretching from 3 to 200 hundred miles offshore – will be open for the production of sustainable seafood.

As a relatively new industry, aquaculture may also be more embracing of innovative technologies and methods, of which satellite can play an important role (in identifying potential sites, guarding against algal blooms, etc).

Running alongside aquaculture growth, in 2016 the UN reported that "almost a third of commercial fish stocks are now overharvested at biologically unsustainable levels". The clear trend to help address this challenge is for more robust regulation (especially Marine Protection Areas) to help to manage fish stocks more effectively.

Sustainability issues notwithstanding, Illegal, Unregulated and Unreported fishing presents an annual cost to the global economy of $23.5 billion. Smarter and more effective surveillance techniques are required, and satellite capabilities may play a vital role in identifying issues, supporting navigation, creating layers of situational awareness both via earth observation and cueing and controlling remote assets to ground truth.

7.2. Maritime border and security

The second area of greatest promise is the global maritime border and security market, which is estimated to grow to $23.67 Billion by 2021, from $16.71 billion, at a CAGR of 7.2%. This growth

will be driven by increasing incidents of piracy and marine terrorism on vessels, ports, and other critical infrastructure.

The surveillance and tracking technology segment is predicted to have the largest market share and dominate the maritime safety market from 2016 to 2021. North America will lead, with significant opportunities also to be found in APAC, due to extensive expansion of regional port capacities and development of maritime security regimes, particularly in countries such as India, China, and Singapore.

These two markets therefore warrant the greatest additional exploration, followed by the marine environmental observation, hydrography and bathymetry and marine leisure markets.