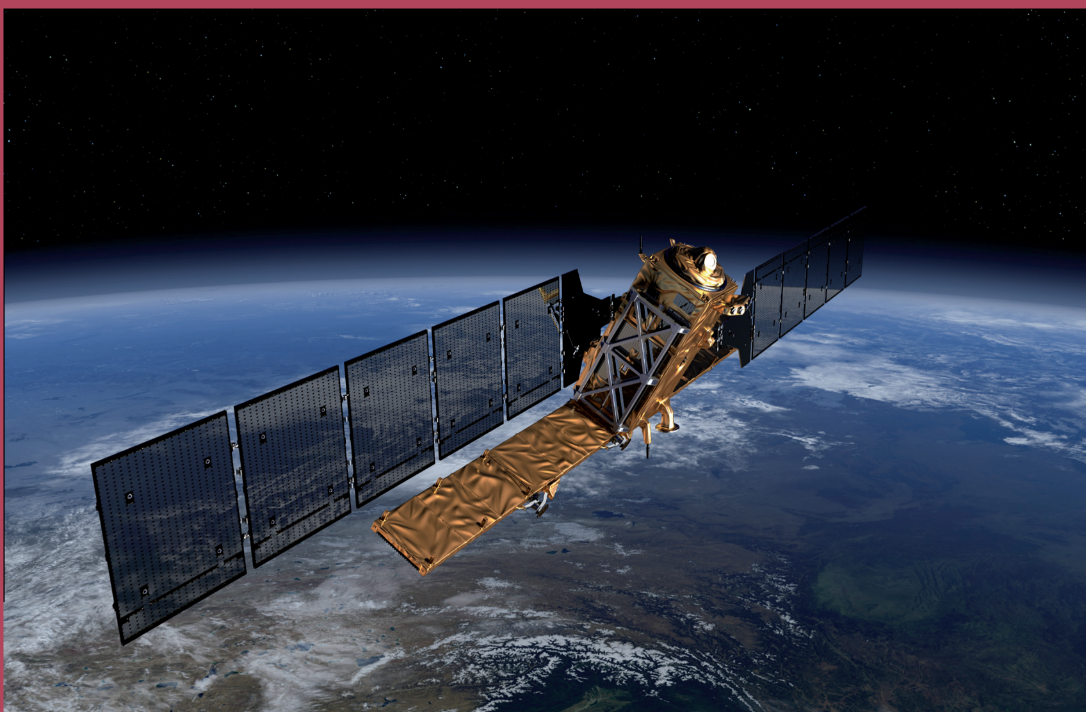
Food and Agriculture Organization of the United Nations

Guidance on spatial technologies for disaster risk management in aquaculture

A Handbook



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Copernicus Programme satellite constellation

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Pictured is Sentinel-1, a radar sensor that is particularly useful for acquiring data for emergency management because it may be used in all weathers and is able to penetrate clouds. This is important because global aquaculture activities mainly take place in tropical and subtropical areas which are almost always cloudy.

Guidance on spatial technologies for disaster risk management in aquaculture

A Handbook

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Abstract

This new guide describes the application of spatial technology to improve disaster risk management (DRM) within the aquaculture sector. DRM requires interrelated activities to ensure prevention, preparedness (including early warning), response and recovery for a wide range of natural, technological and complex disasters that can impact aquaculture operations and livelihoods. Prevention refers to measures aimed at reducing vulnerability to natural and other risks that could result in disasters. Preparedness means having spatial technology in place for rapid response to events and the capability to muster the resources to apply the technology, including leadership, communications and coordination. Early warning systems provide advance notice and enable mitigating actions. Timely disaster response is required when a disaster event commences, and continues throughout the event. The response phase could last from days to months, depending on the magnitude of the disaster, after which the focus turns to recovery and building resilience to future events.

Spatial technology refers to systems and tools that acquire, manage and analyse data that have geographic context. Some of the technologies include satellite remote sensing, aerial surveys, global positioning systems, geographic information systems, information and communication technology and other data gathering sensors used, for instance, in meteorology. Spatial technology, like many other information technologies, is developing rapidly. The revolution in computing and communications technology has changed the risk paradigm through widespread usage of location-enabled and Internet-connected devices establishing a global network of interconnectivity.

Spatial technology supports activities across all phases of the DRM cycle within the aquaculture sector. These activities include disaster risk reduction through prevention, preparedness, and early warning; emergency response to assess and respond to immediate damage and needs and protect livelihoods; recovery for rehabilitation and building back better; and monitoring and assessment of the recovery progress and impact.

This publication is organized in two parts. Part one is the “guidance”; it is the main body of the document and describes the processes and steps for the use of spatial technology within DRM for aquaculture. It considers factors such as accessibility, limitations, complementary data and tools, human resources and financial resource requirements.

Part two includes selected country case studies from Bangladesh, the Gulf of Mexico and the Caribbean, and Indonesia to illustrate the application of spatial technology in DRM for aquaculture at the national level within local contexts. Take-home messages from each case study include recommended steps for using spatial technology to support the DRM process, or parts of the process.

Best practices at the farm and area management levels supported by spatial technology will reduce volatility and risks and thus facilitate investment. Countries that want aquaculture to grow sustainably and reliably should consider using this guide in order to support spatial planning approaches and protect responsible investors. A separate summary version accompanies this publication.

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Foreword

Aquaculture is exposed to many risks resulting from climate extreme events, natural, technological and human-induced hazards. These risks, which may be both recurrent and geographically localized, affect both onshore and offshore aquaculture activities. And, in the context of climate change, the frequency and magnitude of climate-related hazards are expected to increase. As a result, the exposure of aquaculture activities to these phenomena is also predicted to increase, with concomitant escalations in post-disaster damages and losses. It should also be noted that climate change is an aggravating factor for sanitary risks in the aquaculture sector.

According to statistics presented by the Food and Agriculture Organization of the United Nations, between 2003 and 2013, agriculture accounted for almost 22 percent of the damage caused by natural hazards and related disasters in developing countries.[1] Damages incurred by the fisheries and aquaculture sectors amounted to 7 percent, but these sectors are often under-reported in post disaster needs assessments.

The Sendai Framework for Disaster Risk Reduction – the global plan to reduce disaster losses by 2030 –recognizes the primary responsibility of States in reducing and preventing disaster risks, the need for approaches that involve the whole of society, including all public and private institutions, as well as the importance of spatial technologies.

Spatial technologies, such as satellite remote sensing, global positioning systems, aerial surveys, drones, underwater vehicles and sensors, geographic information systems and information and communication technologies, provide information on location-based disaster risks, including risk-based maps, detailed damage assessment, emergency communication, finding suitable sites for building back better, and so on.

In aquaculture, spatial technologies have been used for some time, but there are no specific guidelines for their application in disaster risk management for aquaculture. This Guide intends to fill that gap by providing general guidance for policymakers and other stakeholders on the specific use of spatial technologies for disaster risk management in the aquaculture sector. It aims to illustrate technologies used in other sectors that could be used in aquaculture, as well as informing other sectors, such as fisheries, of the technologies that have been successfully applied in aquaculture. This publication complements the other three fisheries publications on the same subject, namely: Westlund *et al.*, 2007;[2]

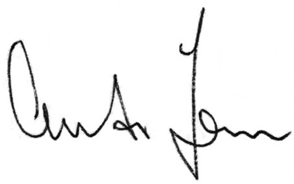
1 FAO. 2018. The impact of disasters and crises on agriculture and food security 2017. Rome. 143 pp.

2 Westlund, L., Poulain, F., Bage, H. & van Anrooy, R. 2007. Disaster response and risk management in the fisheries sector. FAO Fisheries Technical Paper No. 479. Rome, FAO. 56 pp.

Brown and Poulain, 2013;[3] and Cattermoul, Brown and Poulain, 2014.[4] It describes the major steps required to use spatial technologies for disaster risk management in aquaculture. The rationale and the methodologies for implementing disaster risk management, and the spatial tools that are available, are described in a stepwise fashion.

The benefits of using spatial technologies are numerous and include the more effective mitigation of the impacts of environmental, economic and social risks, details of which are provided in this Guide.

The importance of disaster risk management for the resilience of people who derive their livelihoods from the aquaculture and agriculture sectors is reiterated throughout this Guide, as is the need for other sectors to conduct similar studies and share their experiences.



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[3] Brown, D. & Poulain, F., eds. 2013. Guidelines for the fisheries and aquaculture sector on damage and needs assessments in emergencies. Rome, FAO. 114 pp.

[4] Cattermoul, B., Brown, D. & Poulain, F., eds. 2014. Fisheries and aquaculture emergency response guidance. Rome, FAO. 167 pp.

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Abbreviations and acronyms

ASIMUTH	Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms
AUVs	Autonomous Underwater Vehicles
DaLa	damage, loss and needs assessment
DEM	Digital Elevation Model
Disasters Charter	International Charter Space and Major Disasters
DRM	Disaster risk management
DRR	Disaster risk reduction
ERMA	Environmental Response Management Application
EPA	Environmental Protection Agency
ESA	European Space Agency
Esri	Environmental Systems Research Institute
GIS	geographic information systems
GLCF	Global Land Cover Facility
GPS	global positioning systems
HAB	harmful algal bloom
HOT	Humanitarian OpenStreetMap Team
ICT	information and communications technology
JPL	Jet Propulsion Laboratory
LiDAR	Light Detection and Ranging
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NASO	National Aquaculture Sector Overview
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
OCHA	Office for the Coordination of Humanitarian Affairs
Radar	Radio Detection and Ranging
ROVs	Remotely Operated Vehicles
SDI	Spatial data infrastructure
TAPAS	Tools for Assessment and Planning of Aquaculture Sustainability
UAV	unmanned aerial vehicle
UNISDR	United Nations Office for Disaster Risk Reduction
UNITAR	United Nations Institute for Training and Research
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNOSAT	UNITAR's Operational Satellite Applications Programme
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
USGS	United States Geological Survey

Spatial technologies and their application for disaster risk management in aquaculture

Dean, A., Aguilar-Manjarrez, J., Bueno, P.B, Poulain, F. & Pierce, B. 2018. Spatial technologies and their application for disaster risk management in aquaculture. *In J. Aguilar-Manjarrez, L.C. Wickliffe & A. Dean, eds. Guidance on spatial technologies for disaster risk management in aquaculture. A Handbook*. Rome, FAO. 120 pp.

1. INTRODUCTION

1.1 WHY DO WE NEED SPATIAL TECHNOLOGIES FOR DISASTER RISK MANAGEMENT?

World aquaculture production continues to grow and now provides half of all fish for human consumption (FAO, 2016a). The growth of the sector is showing no sign of slowing down in absolute terms (Engle *et al*., 2017) and aquaculture is becoming an increasingly important user of space and natural resources.

Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding and protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated, the planning, development and operation of aquaculture systems, sites, facilities and practices, and production and transport. Aquaculture activities occur in inland, coastal and marine environments that are exposed to a wide range of natural, technical and complex hazards. Disaster risk to aquaculture operations and livelihoods is a function of hazard, and the vulnerability and exposure of the community or society to the hazard (Westlund *et al*., 2007). Vulnerability and exposure are dynamic, varying across temporal and spatial scales. For instance, an aquaculture facility may be relatively sheltered and have low risk to local hydrodynamic forces, but disaster risk increases if it is located where a high frequency and magnitude of significant storm events occurs. Due to the importance of geographic location as a component of disaster risk, spatial technologies have a critical role to play in emergency prevention, mitigation, preparedness, early warning, response and recovery in the aquaculture sector.[1]

[1] Disasters tend to affect population groups that are among the poorest and most marginalized, often simply because these people live in areas that are more exposed to the risk of disasters.

This guide synthesizes spatial technology concepts and describes the application of processes, tools and best practices in emergency preparedness and response in the aquaculture sector.

1.2 THE ORIGINS OF THIS GUIDE

Three documents from the Food and Agriculture Organization of the United Nations (FAO) provide guidance for emergency response in the aquaculture sector:

- Disaster response and risk management in the fisheries sector (Westlund *et al.*, 2007) gives an overview of the lessons learned and experience gained in emergency response and provides recommendations to assist governments and those working in disaster and emergency situations on how to improve disaster response, preparedness and prevention.
- Guidelines for the fisheries and aquaculture sector on damage and needs assessments in emergencies (Brown and Poulain, 2013) provides advice and a structure for assessing the requirements of relief and rehabilitation relating directly to fisheries and aquaculture, including pre-emergency baseline assessments and post-emergency needs assessments.
- Fisheries and aquaculture emergency response guidance (Cattermoul, Brown and Poulain, 2014) aims at helping those responding to emergency situations in fisheries and aquaculture to improve the quality of the design, implementation and assessment of interventions. It covers best practices and experience that are specific to the fisheries and aquaculture sector. The technical interventions covered are grouped according to fisheries and aquaculture policy, fisheries management and fishing operations, aquaculture development, and post-harvest practices and trade.

Spatial technologies are important in all phases of disaster risk management (DRM), particularly when an emergency occurs. This guide addresses the use of spatial technology to support those responding to an emergency in the aquaculture sector and fills knowledge gaps in different areas and for different types of disasters. It describes the principles for using spatial technology as a tool in DRM, thereby ensuring that the guide remains relevant even with ongoing technological advancement. Furthermore, with continuing advances in spatial technology, this guide includes emerging technology that may further expand and strengthen the scope of present technologies.

1.3 WHO SHOULD USE THIS GUIDE?

This FAO Guidance on spatial technologies for disaster risk management in aquaculture is intended for decision-makers and managers working in the aquaculture sector, as well as technical personnel involved in DRM for aquaculture. It provides support for:

- **Planners –** the Guide provides a framework for government, aquaculture producers and insurers to plan and use spatial technologies and data for DRM.
- **Implementers** – the Guide provides assistance to consultants or staff of organizations tasked with using spatial technology. It demonstrates how this technology can facilitate damage assessment and timely and accurate

technical decision-making in DRM for aquaculture, including response and recovery planning.
- **Monitoring and evaluation officers** – the Guide improves understanding of how spatial technology can contribute to monitoring and evaluation of response and recovery efforts in aquaculture.

1.4 WHAT DOES THIS GUIDE COVER?

The guide provides concepts and technical information regarding spatial technologies for DRM, focusing on the following types of spatial technologies:

- **Remote sensing technologies**, including satellite images, aerial surveys and drone-acquired information.
- **Geographic information systems** (GIS) technologies, comprising data collection, analysis and visualization, as well as the use of GIS with mobile devices.
- **Information and communications technologies** (ICT) that integrate or support spatial technologies such as addressing tools, mobile devices, cloud-based data systems, crowdsourcing, Sensor Web for the Internet of things, and models and simulations.

Describing how these technologies can be used throughout the DRM cycle, the guide includes disaster risk reduction (DRR), emergency response, recovery and rehabilitation, and monitoring and assessment. It provides case studies and examples of spatial technology that are specific to aquaculture, but also includes examples of new technology used for infrastructure and security in other sectors such as agriculture, which may translate well for use in the aquaculture sector.

While disasters that impact aquaculture may also impact other sectors such as small-scale fisheries in coastal areas, this guide focuses on aquaculture. However, many of the concepts discussed and the technologies are applicable to other sectors, including small-scale fisheries.

1.5 HOW TO USE THIS GUIDE

- Chapter 2 introduces spatial technology and DRM, including the DRM cycle and the types of spatial technology.
- Chapter 3 focuses on how to use spatial technology, including checklists for each stage of the DRM cycle.
- Chapter 4 illustrates the potential of spatial technology for communication and coordination.
- Annexes contain links to available spatial data, resources and tools; technical support and training materials; and case studies from Bangladesh, the Gulf of Mexico and the Caribbean, and Indonesia.
- A separate summary version accompanies this publication (Aguilar-Manjarrez, Wickliffe and Dean, 2018).[2]

[2] Aguilar-Manjarrez, J., Wickliffe, L.C. & Dean, A., eds. 2018. *Guidance on spatial technologies for disaster risk management in aquaculture. Summary version.* Rome, FAO. 34 pp. Licence: CC BY-NC-SA 3.0 IGO. (also available at www.fao.org/3/CA2659EN/ca2659en.pdf).

2

Spatial technology in disaster risk management

Over the past 50 years, there has been an unremitting growth in computing power in terms of processing speed, data storage capacity, analytical and computer graphics capability. Likewise, application and use of information technologies is growing, especially spatial technology. The revolution in ICT, including computers, location-enabled and Internet-connected mobile devices and the numerous services associated with them, has transformed many processes that can be used in DRM for aquaculture. Continuing advances in remote sensing (e.g. satellites and drones) and GIS provide opportunities for new and improved DRM for aquaculture.

The first step to knowing how spatial technologies can be applied in DRM in the aquaculture sector is to gain a clear understanding of the DRM cycle. Additionally, one must have an awareness of the types of disasters impacting aquaculture and understand how each disaster event can impact aquaculture operations.

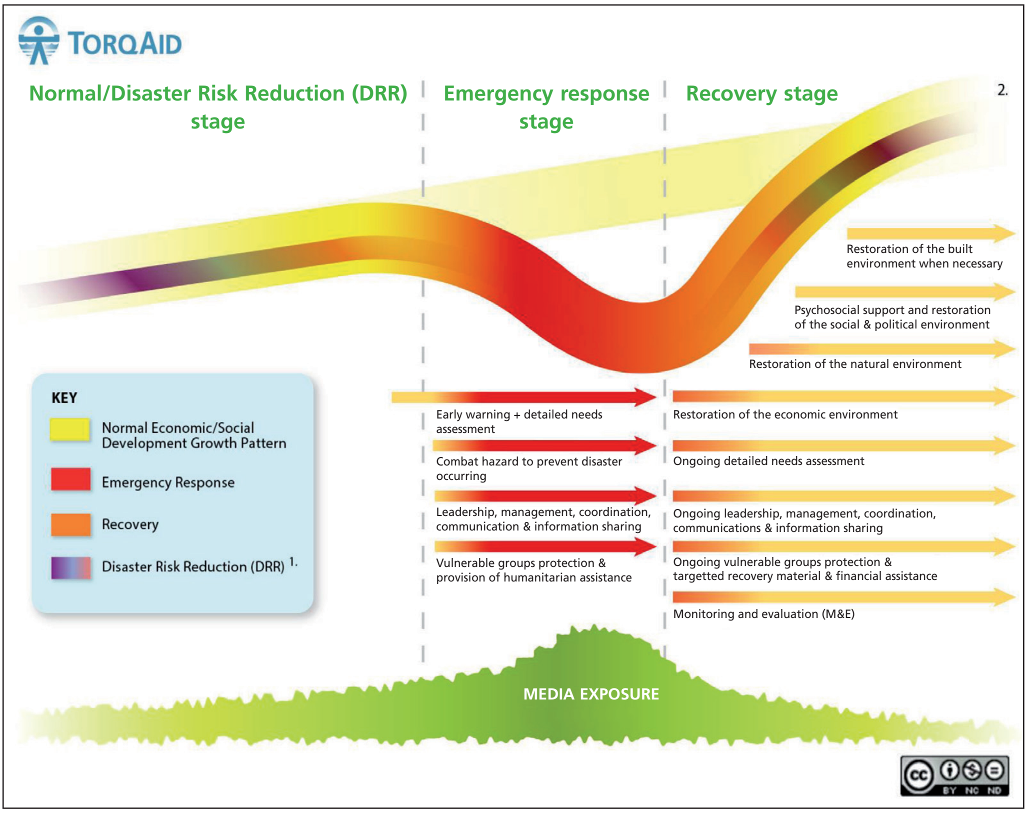
2.1 UNDERSTANDING THE DISASTER RISK MANAGEMENT CYCLE

Many types of hazard may adversely impact aquaculture resources, facilities and processes – exposure to hazards may impact total production and pose a substantial risk to sustainable aquaculture and livelihoods. A disaster is said to occur when hazard exposure leads to severe impacts and consequences impairing major functions – causing loss of assets, support systems, as well as people and personnel, which require a significant amount of resources, effort and time to restore to normality (Baas *et al.*, 2008).[3]

Reducing the likelihood of a hazard occurring, mitigating the impact of a hazard, or coping with the impact of a hazard event are important concerns for aquaculture planners and managers. The DRM cycle (Figure 1) provides a framework to understand these concerns.

[3] Another definition used by the United Nations Office for Disaster Risk Reduction (UNISDR) describes a disaster as "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources." (UNISDR, 2007).

FIGURE 1 **The disaster risk management cycle**



Source: Modified from TorqAid (2018).

Notes:
1. For details of this see the slow-onset Disaster Risk Reduction (DRR) diagram see www.torqaid.com/resources
2. Ideally in the recovery stage the community is able to "Build Back Better"

Disclaimer:
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Disaster risk management includes:

- DRR – the application of DRR policies, strategies and activities to prevent new disaster risk, reduce existing disaster risk, and manage residual risk,[4] contributing to the strengthening of resilience and reduction of disaster losses (UNISDR, 2017). Residual risk management includes financing instruments, such as insurance and reinsurance and social safety nets. DRR can be carried out prior to a disaster to reduce risk, or after a disaster strikes, to reduce future vulnerability.
- Emergency response – the provision of emergency services and public assistance during or immediately after a disaster to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected (UNISDR, 2017).

[4] Residual risk is the disaster risk that remains even when effective DRR measures are in place, and for which emergency response and recovery capacities must be maintained (UNISDR, 2017).

- Recovery and rehabilitation – the restoration and improvement, where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors (UNISDR, 2017).
- Monitoring and assessment - the monitoring and assessment of DRM efforts is important to measure the progress and success of the DRR, response, recovery and rehabilitation of the environment, infrastructure and livelihoods. It should also improve preparedness and response for future events.

The United Nations, including FAO (FAO, 2013) plays an important role in DRM, as explained in Box 1. This guide identifies how spatial technology can be applied across the DRM cycle within the aquaculture sector.

BOX 1

FAO and the Sendai Framework for Disaster Risk Reduction

A study by FAO (2018a) shows that between 2006 and 2016, 23 percent of the total damage and loss caused by medium- and large-scale natural disasters in 53 developing countries occurred in the agricultural sector. FAO's work on DRM focuses on developing, protecting and restoring sustainable livelihoods so that the integrity of societies that depend on farming, livestock, fish, forests and other natural resources is not threatened by disasters and crises. It uses a "twin-track" approach, on the one hand taking immediate steps to protect and support agriculture, food and nutrition, and on the other addressing in the longer term the underlying factors driving risks and disasters. FAO's work on DRM at global, regional, national and local levels is guided by the UN Framework Convention on Climate Change (UNFCCC) and the Sendai Framework for Disaster Risk Reduction (2015–2030) (the Sendai Framework). The Sendai Framework is the outcome of the Third UN World Conference on Disaster Risk Reduction and is succeeding the Hyogo Framework for Action 2005–2015. The Sendai Framework makes specific reference to spatial technologies for the development and implementation of knowledge-based policies and practices. At local and national levels, the Sendai Framework recommends "to develop, periodically update and disseminate, as appropriate, location-based disaster risk information, including risk-based maps, to decision-makers, the general public and communities at risk of exposure to disaster in an appropriate format by using, as applicable, geospatial information technology". At global and regional levels, it is recommended "to promote and enhance, through international cooperation, including technology transfer, access to and the sharing and use of non-sensitive data and information, as appropriate, communications and geospatial and space-based technologies and related services", as well as "disseminate risk information with the best use of geospatial information technology".

Source: FAO (2018a); UNISDR (2016).

Types of disasters and their impacts on aquaculture

A disaster event that puts aquaculture operations and livelihoods at risk for potential disruption or loss of operation can be one of four general types: (i) natural (hydrometeorological, geophysical or biological); (ii) technological; or (iii) complex. In addition, a main driver of climate change impact on aquaculture is exposure to climate extreme events as well as the effect of climate change on the natural resources needed for aquaculture, such as water, feed and space (Barange *et al.*, 2018). The impacts of major disaster types on aquaculture operations vary, as do their implications for livelihoods in the aquaculture sector. The impacts on operations and livelihoods of the major disaster types are summarized from Table 1 to Table 5.

TABLE 1
Natural (hydrometeorological) disaster impacts on aquaculture operations and livelihoods

Disaster type	Impacts on aquaculture	Implications for livelihoods
Hurricanes or cyclones	• Disruption of operations could be from short to prolonged period • Disruption of power if farm is connected to grid • Structures (cages, etc.) damaged • Marketing timetable is upset; cold storage, refrigeration equipment, transport to market could be cut off or disrupted • Loss of farmed plants and aquatic animals	• Destruction or loss of physical assets, and loss or damage to stock • Reduced value of operations • Death and/or health problems of farmers and farm workers degrade human capital
Floods	• Disruption of operations could be from short to prolonged period • Farm-to-market roads could temporarily be rendered impassable • Damage to infrastructure, water intake and outlet systems • A large influx of freshwater can cause massive mortalities of cultured marine species • High water levels or infrastructure damage (e.g. dam wall failure) can result in escape of cultured species • Washing away of coastal and inland aquaculture ponds, cages and associated equipment • Increased eutrophication and algal blooms	• Loss of physical assets and damage to productive capacity of land; reduced value of land • Death and/or health problems of farmers and farm workers degrade human capital • Floods can bring in contaminants that pose risks to human health
Drought and severe heat	• Water supply severely restricted and reduced water quality can lead to reduced production • Cultured species that are not tolerant to high temperatures may die • Pond-based and floating cage freshwater systems cannot always operate	• Prolonged drought may preclude any freshwater aquaculture • Freshwater supply severely restricted, leading to potential water use conflicts
Severe winter	• Cultured species that are not tolerant to cold temperature die • Farm structures are destroyed • Energy supply is disrupted	• Damage to stock; reduced value of operations; low productivity • Cost for rebuilding or improving structures for improved resilience

TABLE 2
Natural (geophysical) disaster impacts on aquaculture operations and livelihoods

Disaster type	Impacts on aquaculture	Implications for livelihoods
Earthquake	• Land-based systems damaged or destroyed; water intake and outlet system could collapse • Farm-to-market roads could be rendered impassable • Support services such as ice supply and refrigeration could be inoperable	• Destruction or loss of physical assets • Damage to productive capacity of land • Reduced value of operations • Cost for rebuilding or improving structures for improved resilience • Death and/or health problems of farmers and farm workers degrade human capital
Volcanic eruption	• Destruction or damage to infrastructure • Boundaries are obliterated leading to problems of land tenure or conflicts over land ownership	• Destruction or loss of physical assets • Damage to productive capacity of land • Reduced value of operations • Death and/or health problems of farmers and farm workers degrade human capital
Tidal surge and tsunami	• Severe disruption of operations • Coastal and inland aquaculture severely damaged; farm structures destroyed; probable death of farmers and farm workers • Local hatcheries would be unable to provide seed; ponds could be silted up or buried in silt; water intake systems could collapse or also be silted up • Boundaries are obliterated leading to problems of land tenure or conflicts over land ownership	• Destruction or loss of physical assets • Damage to productivity • Reduced value of operations • Death and/or health problems of farmers and farm workers degrade human capital • Cost of re-engineering and rebuilding farm structures for improved resilience

TABLE 3
Natural (biological) disaster impacts on aquaculture operations and livelihoods

Disaster type	Impacts on aquaculture	Implications for livelihoods
Disease outbreaks	• Destruction of stocks to prevent spread of pathogens • Limited operation with strict on-farm biosecurity measures • Impacts on broodfishes • Quarantine periods for certain areas or diseases	• Loss of income • Loss of market • Costly health management measures • Temporary loss of production
Harmful algal blooms and hypoxia i.e. includes jellyfish swarms, population explosions of other predatory or harmful animals, or unusual hydrographic events, which result in deoxygenation or release of toxic gases from sediments, etc.)	• Closure of farming areas (molluscs and cage culture) • Early harvest if crop is marketable • Fish kills or contamination of stocks	• Loss of income; loss of market • Costly health management measures • Culture in the affected portion of the waterbody cannot be carried out for an extended period

TABLE 4
Technological disaster impacts on aquaculture operations and livelihoods

Disaster type	Impacts on aquaculture	Implications for livelihoods
Oil spills, chemical spills and chemical runoff	• Fish kills or contamination of stocks • Closure of culture grounds for an extended period until clean-up is complete	• Loss of income; loss of market • Costly health management measures
Nuclear leak	• Contamination of water and soils will force cessation of operations; long-term health hazard from radioactivity exposure	• Loss of income; loss of market • Health problems of farmers and farm workers degrade human capital

Complex disasters (Table 5) are humanitarian crises resulting from military conflict or civil strife in which external assistance is needed in order to help populations deal with the consequences (Brown and Poulain, 2013). Complex disasters can be exacerbated by natural hazards and diseases (e.g. HIV/AIDS).

TABLE 5
Complex disaster impacts on aquaculture operations and livelihoods

Disaster type	Impacts on aquaculture	Implications for livelihoods
Armed conflicts / humanitarian crises	• Complete cessation of farm operations; paralysis of services • Threat to life and property • Possible confiscation or destruction of physical assets	• Loss of income; loss of market • Evacuation and relocation

In addition, the aquaculture sector is facing substantial threats from extreme events and other climate stresses (Barange *et al.*, 2018). The December 2015 Paris Agreement on climate change (Box 2) requires sustained action from developed and developing countries over many decades to combat climate change and adapt to its effects. The Agreement recognizes the importance of technological innovation to understand and reduce climate risks and to address climate change.

Risks and vulnerability of aquaculture to disasters

Aquaculture is practised in varied environmental and physical settings; everyday management of aquaculture operations is complex because of the range of factors that can affect production. All the segments of the aquaculture production and supply chain are vulnerable to disaster events, which makes the tasks of DRR, emergency response, and recovery and rehabilitation particularly demanding. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001) describes vulnerability as a function of exposure, sensitivity and adaptive capacity. Factors that affect aquaculture vulnerability include:

(i) Many aquaculture sites tend to be exposed compared to other industries due to competition for coastal resources and production locations.

BOX 2

December 2015 Paris Agreement on climate change

The Paris Agreement negotiated at the end of 2015 (COP21 of the UNFCCC) was signed by 175 nations in the spring of 2016. The Agreement brings nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort.

The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change through climate change adaptation. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity-building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. The Agreement also strives towards enhanced clarity of action and support through a more robust transparency framework.

Source: United Nations (2018); FAO (2018b).

(ii) Many aquaculture sites are situated in fragile ecosystems that can be susceptible to hydrometeorological changes.

(iii) Conditions for cultured species easily deteriorate with changes in temperature, precipitation and other water quality parameters. The cultured species are often sensitive or have low tolerance to these changes and pathogens may be readily transmitted through the water medium in a manner that may be impossible to control.

(iv) Aquaculture is often the "last user" of freshwater and usually accorded low priority in its allocation.

(v) In many countries, aquaculture is mostly carried out by small-scale and resource-poor farmers with weak resilience and adaptive capacity to disasters.

A variety of indices are available to assess the vulnerability of aquaculture to climate change in the aquaculture sector (Brugère and De Young, 2015). Assessment of the vulnerability of aquaculture and associated industries in the production value chain, including the many associated livelihoods, can be considered at a range of scales, from single farms or small areas, to regional, national and global assessments (Bueno and Soto, 2017).

In 2012, the IPCC (2012) moved from a vulnerability-based framework to a risk management framework, thereby bringing the climate change community closer to the models used in DRM and in the insurance industry. In this understanding, the concept of risk results from the interaction of hazard, exposure and vulnerability (IPCC, 2014). Conceptually, it has been argued that separating exposure from vulnerability can be beneficial to spatial planning because it emphasizes the worth and spatial targeting of exposure reduction measures (e.g. not building in flood risk areas) (Connelly *et al.*, 2018).

2.2 TYPES OF SPATIAL TECHNOLOGY

The use of spatial technology is increasingly prevalent in society, with location-enabled devices and use of Internet-enabled services being a key part of the digital revolution. Spatial technology refers to systems and tools that acquire, manage and analyse data that have geographic or location context. This includes remote sensing technologies, such as satellite images, drones, underwater sensor technologies, aerial surveys, global positioning systems (GPS), GIS, ICT such as smartphones, and other data gathering sensors used in meteorology.

Over the past two decades, ICT has dramatically transformed society and economic development. Society and governments worldwide are aware of the power of ICT for the advancement and transformation of public, private and civil society, and thus it is not surprising that the United Nations 2030 Agenda for Sustainable Development embraced ICT-enabling technologies to address the Sustainable Development Goals.

Building on spatial technology and ICT, several tools and models are developed specifically for DRM, and many can be specifically applied in the aquaculture sector.

Remote sensing

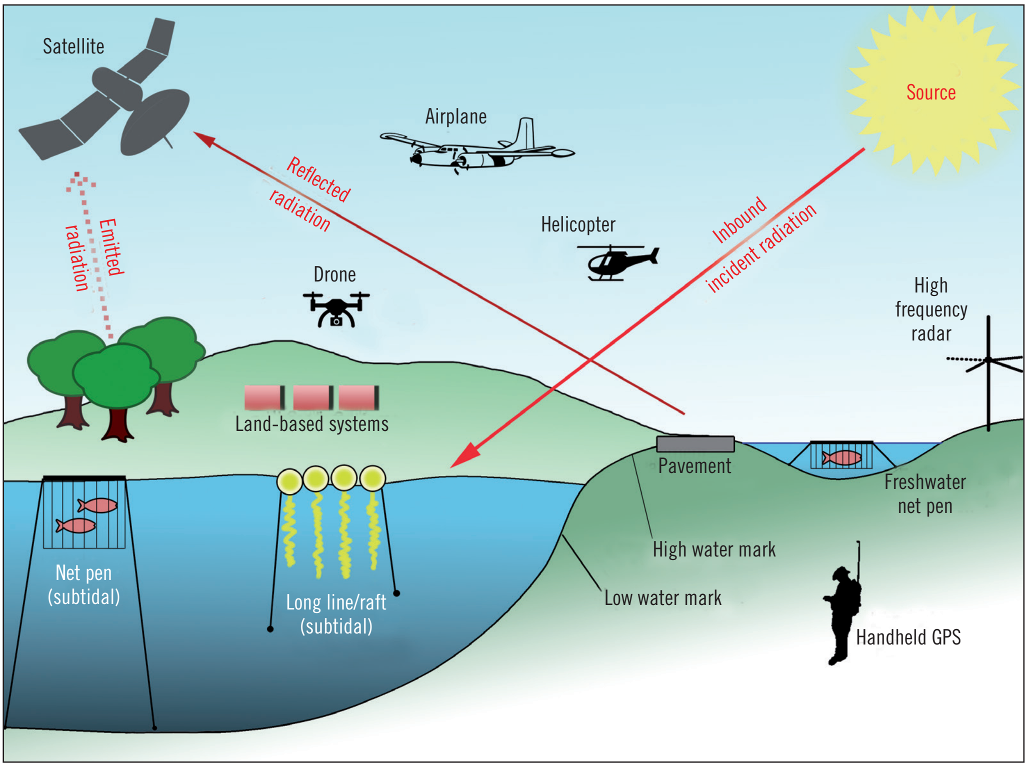
Remote sensing is formally defined as "the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation" (Lillesand, Kiefer and Chipman, 2007; Dean and Populus, 2013).

Remote sensing technology encompasses hardware, software and analytical capabilities to acquire, process and deliver remotely sensed data. Remote sensing requires a platform and sensor. The common platforms are satellites, aircraft and drones, which can carry a variety of sensors to record data. The most common sensors are cameras to capture photographs or images. Data processing using specialized software tools allows remote sensing data to be visualized as digital images, which include geographic coordinates within the image. Visualization is possible using software on a computer or mobile device.

Use of satellite images and drones has increased dramatically in recent years. However, traditional remote sensing methods such as surveys from aircraft remain important in emergency response efforts. The crucial benefit of remote sensing is the observation of large and often remote or inaccessible areas, often at a fraction of the cost of ground-based surveys (Travaglia, Kapetsky and Profeti, 1999).

The process of remote sensing is illustrated in Figure 2. Sensors used to provide remote sensing data can be broadly categorized as passive or active. With passive sensors, the source of energy is usually the sun – e.g. reflected light in the visible spectrum or emitted thermal or microwave energy. Active systems provide their own source of energy and include radar (Radio Detection and Ranging) and LiDAR (Light Detection and Ranging). With passive and active systems, the energy travels through the atmosphere and interacts with the target (e.g. ocean or ground surface). The reflected or emitted energy is received by the sensor and converted into a signal that can be recorded and displayed as an image.

FIGURE 2 **An overview of the process of remote sensing**



The main types of remote sensing systems are the following:

- Optical – passive optical sensors (like our eyes) measure reflected electromagnetic radiation in the visible blue, green and red wavelengths as well as infrared wavelengths (that human eyes cannot detect). In cloudy regions, it may not be possible to observe the Earth's surface because optical wavelengths do not penetrate through clouds.
- Thermal – passive thermal sensors measure energy emitted by the Earth's surface related to temperature. An example of thermal measurement is sea surface temperature.
- Radar – sensors record microwaves and are not affected by cloud cover. Radar can be passive or active, but only active systems provide high spatial resolution data. Radar data are usually processed and interpreted by a specialist into a product that can be used by non-experts.
- LiDAR – active systems create images by recording the interaction of laser light with the Earth. LiDAR is usually processed by specialists or commercial suppliers. The most common LiDAR product is a precise Digital Elevation Model (DEM), which provides accurate topographic and bathymetric information.

Remote sensing provides a range of environmental information useful to aquaculture operations that can be applied across the DRM cycle. Major disaster types and applicable remote sensing measurements for each DRM stage are listed in Table 6. For example, remote sensing can provide wave energy and height information to support DRR. Remote sensing contributes to assessment of hurricanes or cyclones that may pose a risk to aquaculture. For emergency response, remote sensing provides images to support rapid damage assessment; for recovery, remote sensing information can support rehabilitation and reconstruction.

Further information on remote sensing parameters that can be measured for different disaster types is provided in Annex 1. A useful overview of satellite remote sensing and the DRM cycle is provided by Joyce *et al*. (2009).

TABLE 6
Remote sensing applicable to aquaculture disaster risk management

Disaster type	Remote sensing contribution		
	Disaster risk reduction	Emergency response	Recovery
Storms	Baseline sea wave height, wind speed, surface currents	Monitoring of storm impact and rapid observation of impact area	• Monitoring rehabilitation and reconstruction
Tidal surge, tsunami	Near-shore bathymetry, land elevation, and infrastructure and communities	Rapid observation of impact area	• Change in nearshore bathymetry • Coastal zone and land use planning • Monitoring rehabilitation and reconstruction
Floods	Baseline shoreline position, elevation, permanent water extent, and historical flood extent	Rapid observation and monitoring of flood extent	• Flood extent as input to planning • Monitoring rehabilitation and reconstruction
Drought	Baseline of long-term temperature, precipitation, water extent	Observation and monitoring of climate anomalies from baseline	• Water extent, climate data as input to planning
Severe cold	Baseline of long-term water temperature, extent and duration of sea, lake, and river ice	Observation and monitoring of climate anomalies from baseline	• Ice extent, climate data as input to planning
Climate change	Baseline of long-term water supply, freshwater extent, sea surface temperature, sea level, ocean salinity, extreme events	Long-term monitoring of baseline parameters	• Input data to climate change adaptation planning

Disaster type	Remote sensing contribution		
	Disaster risk reduction	Emergency response	Recovery
Volcanic eruptions, earthquakes, tsunamis	Baseline mapping of aquaculture infrastructure and communities	Rapid observation of impact area	• Input data to recovery planning and monitoring • Monitoring rehabilitation and reconstruction
Diseases	Baseline proxy variables such as vegetation health, ocean productivity	Monitoring proxy variables	n/a
Harmful algal blooms	Baseline proxy variables such as chlorophyll-*a*	Rapid observation and change detection of chlorophyll-*a*	Input data to recovery planning
Oil spills	Baseline shoreline mapping, e.g. ecosystem sensitivity mapping	Spill extent using radar, laser fluorescence (air-borne); rapid impact assessment	• Inputs to impact assessment and clean-up planning • Monitoring rehabilitation and clean-up
Chemical pollution	Proxy variables such as vegetation health, chlorophyll-*a*	n/a	• Inputs to impact assessment and clean-up planning • Monitoring rehabilitation and reconstruction
Nuclear	Proxy variables such as vegetation health	Rapid assessment of impacted area	• Input data to recovery planning
Complex disasters: security	Baseline mapping of infrastructure, transport networks	Rapid observation and change detection	• Input data to recovery planning • Monitoring rehabilitation and reconstruction

Source: Adapted from Cattermoul, Brown and Poulain (2014, pages 5 and 111); Siebert (2009).

Satellite remote sensing

National and international satellite remote sensing programmes can provide free and open data, which are complemented by numerous commercial systems. The most important satellite systems for DRM in the aquaculture sector are those that acquire useful data regularly, consistently and across the globe at a suitable spatial resolution. Several remote sensing systems can acquire data quickly at high spatial resolution. The important sensors are summarized in Table 7.

TABLE 7
Commonly used satellite remote sensing technology

Satellite programme	Spatial resolution	Cost (USD)	Availability
Landsat-8 (Landsat programme)	30 m multispectral 15 m panchromatic	Free and open data	Launched in 2014 Long archive from previous satellites going back to the 1970s
Sentinel-2 (Copernicus programme)	10 m multispectral	Free and open data	Launched in 2015
RapidEye	5 m multispectral	Roughly USD 1.5 per sq km	Launched in 2008
SPOT-6 and -7	1.5 m multispectral	Roughly USD 5 per sq km	Launched in 2012 and 2014 Long archive from previous satellites
WorldView-2, -3 and -4	30 to 50 cm multispectral	Roughly USD 12 to USD 40 per sq km	Launched in 2009, 2014 and 2016 Long archive from previous satellites

Notes: Multispectral: related to two or more frequencies or wavelengths in the electromagnetic spectrum. Panchromatic: a single band image generally displayed as shades of grey.

The spatial resolution of satellite images can be confusing, because “high”, “medium” and “low” resolution are relative terms. An overview of spatial resolution is provided in Table 8. When reviewing remote sensing data and products, another common term is the “product level”, which refers to the type of processing already completed to the original data received by the satellite sensor. An overview of the processing levels of satellite image data is provided in Table 9.

TABLE 8
Satellite system sensor resolution ranges

Resolution	Range
Very high resolution 1	≤ 1 m
Very high resolution 2	1 m < x ≤ 4 m
High resolution 1	4 m < x ≤ 10 m
High resolution 2	10 m < x ≤ 30 m
Medium resolution 1	30 m < x ≤ 100 m
Medium resolution 2	100 m < x ≤300 m
Low resolution	≥ 300 m

Source: Modified from ESA (2018). https://spacedata.copernicus.eu/web/cscda/data-offer/mission-groups

TABLE 9
Common remote sensing imagery data levels

Level	Description
1A	Unprocessed instrument data at full resolution.
1B	Instrument calibrations have been applied to Level 1A data to provide more consistent values.
2	Derived variables at the same resolution as the source Level 1 data, e.g. sea surface temperature data, where the spatial resolution of the data may vary across the image.
3	Derived variables in a regular grid formation, e.g. a regular grid of sea surface temperature data. Level 3 data are sometimes called "binned" because they have a regular grid, or "mapped" if they have been map projected.

Source: Adapted from the NASA (National Aeronautics and Space Administration). 2018. Ocean Color Web. Product Definitions. In: NASA. [online]. United States of America. [Cited 8 October 2018]. https://oceancolor.gsfc.nasa.gov/products.

When a disaster occurs, rapid observation of the affected area is important for emergency response and impact assessment. Most satellite remote sensing systems cannot observe the same location on the Earth's surface every day. Commercial satellite systems often provide more frequent coverage or flexibility to focus the sensor on a particular location. For example, RapidEye is a constellation of five satellites with high-resolution sensors, whereas WorldView is a constellation with a very high-resolution sensor that can be steered towards a location of interest, increasing the opportunities to observe a disaster area. More recently, companies have begun to develop constellations of hundreds of small-sized "micro" satellites (each weighing less than 10 kg) that aim to provide daily high-resolution images for the entire planet (see Figure 3).

In combination, free and commercial satellite remote sensing systems can capture imagery very quickly following a disaster event. Recognizing the importance of satellite imagery, international space agencies and commercial operations signed the International Charter Space and Major Disasters ("Disasters Charter"), which ensures that images are captured and made available for free following major disasters (see section 2.4). Many national and international agencies also conduct emergency response mapping using the Disasters Charter imagery to provide maps and information that are easy to use by those without remote sensing expertise.

An example of a high-resolution optical satellite image acquired by the company Planet is shown in Figure 3. Since 2016, Planet has launched hundreds of micro satellites with the goal of daily image acquisition for the entire planet, which would be a valuable capability for emergency response. Its constellation and access platform became available for use in 2017.

FIGURE 3 **Planet satellite image of aquaculture ponds in China's Bohai Sea**

Source: Planet (2018).

Note: Latitude: 40°7′17.91″N; Longitude: 120°11′7.70″E.

Satellite remote sensing software

Remote sensing images can often be obtained in a format ready to use in GIS or other non-specialist mapping or image analysis software. Following a disaster event, remote sensing images are often publicly available online in a user-friendly map viewer or used to produce maps by agencies that support the Disasters Charter (see section 2.4).

Some users in the aquaculture sector may want to view and process remotely sensed images, and a range of commercial and open source remote sensing software options provide basic and sophisticated image processing tools. Open source remote sensing products are software with its source code available for free with licence rights to study, change and distribute the software to anyone and for any purpose (Open Source Initiative, 2018). A selection of commonly used commercial and open source remote sensing software is presented in Table 10. Although these software packages are not specific to DRM, each may play a role across the DRM cycle.

Globally, people are generally familiar with Google Earth as a method to view GIS data and remotely sensed images. Google Earth, Google Earth Pro and Google Earth Web are free desktop software that are widely used in many applications; although they are not specific to DRM, they may play a critical

role in a DRM phase. To find out when new imagery is available in Google Earth, see Follow Your World (Google, 2018a).

While Google is active in supporting emergency response, for example the 2010 Haiti earthquake (Google, 2018b), the imagery provided through Google Earth is most suitable at the DRR stage of the DRM cycle. Historical imagery can be viewed in Google Earth, which can serve as a baseline for comparing areas before they were impacted by a disaster event. Google Street View (Google, 2018c) may also be valuable for assessing damaged areas before damage occurred. Google Earth Outreach gives non-profits and public benefit organizations knowledge and resources on Google Earth and Maps (Google, 2018d).

TABLE 10
Commonly used remote sensing software applicable to aquaculture disaster risk management

Name	Publisher	Licence/ cost	Description	Complexity rating
ILWIS	52°North open source software initiative	Open- source $	Free integrated *raster and vector GIS and remote sensing software	▪▪
Sentinel toolboxes	European Space Agency (ESA)	Open- source $	Free open source toolboxes for the scientific exploitation of Sentinel missions	▪▪▪
IDRISI	Clark Labs	Commercial $$	GIS tool set with over 300 analytical tools, primarily oriented to raster data	▪
ENVI	Exelis Visual Information Solutions	Commercial $$$	Software to process and analyse all types of imagery	▪▪
ERDAS Producer Suite	Hexagon Geospatial	Commercial $$$	Software to process and analyse all types of imagery	▪▪
Geomatica	PCI Geomatics	Commercial $$$	Software to process and analyse all types of imagery	▪▪

Notes: Cost rating: $$$ = > USD 5 000; $$ = ≤ USD 5 000; $ = free.
Complexity rating: ▪ = beginner user, training manuals; ▪▪ = expert user, good documentation; ▪▪▪ = expert user.

*A "raster" is a spatial data model that defines space as an array of equally sized cells arranged in rows and columns, whereas a "vector" is a coordinate-based data model that represents geographic features as points, lines, and polygons (see Meaden and Aguilar-Manjarrez, 2013).

Global positioning systems

GPS are positioning and navigation systems for determining locations using signals from a network of satellites orbiting Earth. GPS work anywhere around the planet, including remote locations with a clear enough view of the sky to receive signals from at least three or four GPS satellites. Common uses of GPS include vehicle navigation, tracking the location of business assets, and mapping for outdoor recreation (e.g. hiking, hunting and fishing).

Popular brands of consumer grade GPS receivers include Garmin, Magellan, Tom Tom, Bad Elf and Lowrance. Prices range from about USD 90 for a basic handheld model to over USD 1 000 for a high-end surveying or navigation system. Key differentiators include built-in maps, computer connectivity and the ability to automatically calculate routes to a destination. GPS receivers are commonly integrated into communication devices such as smartphones and tablets.

Information collected during humanitarian assessments is more valuable with precise location data. Recording geographic coordinates avoids issues such as using a place name (e.g. a village visited) – what if that village does not appear with that name on other maps? What if there are two places with the same name (which is amazingly common)? With a GPS receiver, it is possible to record the geographic coordinates of a location.

A GPS can be used to capture the location and extent of damage during a field survey, and if an aerial assessment of damaged areas is completed, the GPS can indicate the location of damage to specific areas, structures or culture facilities observed in reconnaissance photographs.

Aerial survey

Aircraft surveys and aerial photography are commonly applied for baseline mapping projects by national mapping agencies. These photographs and maps make an important contribution to DRR. Aerial surveys are common following a disaster for immediate reconnaissance or inputs for map updates in the emergency response. Aerial photos provide very high-resolution images (e.g. 10 to 30 cm), often better than the highest resolution satellite imagery. Flights can also be planned and implemented quickly.

Aerial “visual” surveys are also common in disaster response (see Figure 4), since specialized survey aircraft and equipment are not required. These visual surveys also need to be planned and follow a clear method to record the observations made by the survey team, e.g. using maps and a checklist to capture the observed disaster impacts. For example, FAO’s Bangladesh Food Security Cluster conducted aerial assessments during 2015 to obtain a quick understanding of the impacts of floods and cyclones. An aerial assessment form (checklist) was used to estimate the level of impacts on

FIGURE 4 **Aerial survey of damage following the Japan tsunami of 2011**

Aerial survey photo

Aerial reconnaissance

Source: U.S. Pacific Fleet (2016).

key infrastructure (e.g. vehicle activity, accessibility to market, telephone and power lines, major roads cut off, and fish pond conditions).

To be prepared for disaster events, in the DRR phase aerial photo standards and specifications should be defined and shared with potential suppliers. Pre-qualification of suppliers in different regions of the country can be made against the standards to reduce mobilization time for disaster response. In many cases, permits may be required (sometimes with the approval of the military to fly over certain areas and such procedures must be planned in advance.

Drones or unmanned aerial vehicles

One area of innovation for real-time aerial imagery and remote sensing are drones and unmanned aerial vehicles (UAVs). The companies, platforms and capabilities of systems, along with the rules for public and private use, are evolving rapidly. The emergence of small, affordable drones and advances in highly automated mapping promise new capabilities for humanitarian action (see Box 3), including DRM and applications in the aquaculture sector. Due to their rapid and easy deployment, drones are most appropriate for short-notice acquisition of very high-resolution images (e.g. 5 cm to 20 cm) over small areas (a few square kilometres) in support of emergency response. Highly automated and precise drone navigation and automated image processing and mapping reduce the barriers to entry for acquisition and processing tasks that are typically performed by specialists and national mapping agencies.

BOX 3

Drones in Humanitarian Action

The Drones in Humanitarian Action is a 21-month action to consolidate existing knowledge on the use of drones in the humanitarian context. The partners intend to test, promote and disseminate the appropriate use and best practices among United Nations clusters, non-governmental organizations and other relevant stakeholders (FSD, 2017). The initiative is led by the Swiss Foundation for Mine Action in partnership with CartONG, Zoï Environment Network, and the Humanitarian UAV Network.

The Humanitarian UAV Network website also contains a wealth of information around the use of UAVs in humanitarian contexts (UAViators, 2018)

Drone use for disaster response includes sophisticated government/military systems to low-cost commercial quadcopters and microlights (typically called drones).

The size of a drone can vary greatly and dictates several factors relating to its performance and the information that it can obtain. Table 11 lists commonly used drones applicable to aquaculture DRM according to their cost, complexity, flight time and add-ons to increase its capabilities. Fixed-wing drones tend to have greater endurance and can be used to map larger areas, whereas quadcopters and hexacopters are more maneuverable in small areas, e.g. for building inspections.

TABLE 11
Commonly used unmanned aerial vehicles applicable to aquaculture disaster risk management

Type	Model	Cost	Complexity rating	Flight time	Add-ons	Image
QC	DJI Phantom	$	▪	✈	No	
QC	DJI Mavic	$	▪	✈	No	
QC	DJI Matrice	$$$	▪▪▪	✈✈	Yes (camera, sensors, additional payload)	
QC	3DR Solo	$$	▪▪	✈	Yes (changeable cameras – MAPIR)	
QC	Parrot Bebop	$	▪	✈	No	
HC	DJI Spreading Wings	$$$	▪▪▪	✈✈	Yes (camera, sensors, additional payload)	
HC	Tarot Hexacopter	$$$	▪▪▪	✈✈	Yes (camera, sensors, additional payload)	
FW	eBee	$$$	▪▪	✈✈✈	Yes (camera, sensors, additional payload)	
FW	MyFlyDream MFD Fixed Wing Nimbus	$	▪▪	✈✈✈	Yes (camera, additional payload)	
FW	Parrot Disco Drones	$	▪▪	✈✈✈	No	
QC	Micro drones	$ $	▪▪	✈✈	Yes (camera– MAPIR)	

Notes:
QC = quadcopter; HC = hexacopter; FW = fixed wing.
Cost rating: $$$ = > USD 10 000; $$ = ≤ USD 5 000; $ = ≤ USD 1 000.
Complexity rating: ▪ = beginner user; ▪▪ = expert user, good documentation; ▪▪▪ = expert user.
Flight time rating: ✈ ✈ ✈ > 1 hour; ✈ ✈ = ≤ 30 minutes; ✈ = ≤ 15 minutes.

Drones include digital cameras, with more sophisticated UAVs including thermal and/or LiDAR sensors. Survey and engineering companies employ drones to obtain very high-resolution (e.g. 5 cm) georeferenced images and digital elevation surfaces. Small drones (e.g. quadcopters) can be controlled by on-site operators with limited training to assist in emergency response, while sophisticated UAVs could be deployed from a central control site. Box 4 provides example drone images following a disaster affecting aquaculture facilities in Washington State, United States of America.

BOX 4

A drone image of a damaged salmon cage near Cypress Island in Washington state's Puget Sound (United States of America)

Due to a combination of factors, including extensive biofouling, anchor dragging and insufficient structural repairs on the framing of the fish cage, the weakened structure collapsed in Washington State waters on 19 August 2017.

Source(s):
Clark, D., Lee, K., Murphy, K. & Windrope, A. 2017. Cypress Island Atlantic Salmon Net Pen Failure: An Investigation and Review. Washington Department of Natural Resources, Olympia, Washington, United States of America.

CBC News. British Columbia, 23 August 2017.
www.cbc.ca/news/canada/british-columbia/cooke-aquaculture-collapse-fish-farm-1.4259083

Drones, designed to be agile, fast and robust, give response teams a significant advantage without costing as much as manned flight operations. Because drones can be programed for autonomous or preplanned flights, they can access areas that are difficult to reach and perform data gathering tasks

that are otherwise unsafe or impossible for humans. Therefore, drones are very valuable tools for DRM. Drones can also improve mobile and Internet connectivity for emergency services and consumers. Poor mobile signal in rural areas is frustrating, but it can also be life threatening in emergency situations. Slow emergency response times mean higher mortality rates. For the last two years, the Finnish tech firm Nokia and the British mobile operator EE have been flying small quadcopter drones mounted with portable mobile base stations in Scotland, the United Kingdom of Great Britain and Northern Ireland. The idea is that in an emergency, a drone could hover over a disaster area and provide instant 4G mobile network coverage with a 50 km radius. United States telecom provider AT&T is developing a large helicopter-like drone known as the Flying COW (Cell on Wings). It is tethered to the ground by a cable that gives it power, which enables the drone to stay in the air 24 hours a day at a maximum height of 168 metres. AT&T says that it used Flying COW to provide emergency 4G coverage to Puerto Rico in the aftermath of Hurricane Maria in November 2017. Each drone was able to cover an area measuring 36 km2 (Russon, 2018).

A selection of commonly used software for UAVs is presented in Table 12. These software packages may play a role across the DRM aquaculture cycle.

TABLE 12
Commonly used software for unmanned aerial vehicles applicable to aquaculture disaster risk management

Name	Function			Type			Cost	Complexity rating
	Planning	Mission	Post process	App	Desktop	Cloud		
DJI GO	+	+	-	+	-	-	$	▪
Pix4D Capture	++	++	-	+	-	-	$	▪▪▪
Pix4D Mapper	-	-	++	-	++	++	$$$	▪▪▪
ArduPilot Mission Planner	++	++	-	++	-	-	$	▪▪
Agisoft PhotoScan	-	-	++	-	++	-	$$$	▪▪
Drone2Map for ArcGIS	-	-	+	-	++	++	$$	▪
DroneDeploy	+	+	-	++	-	++	$$	▪▪
Open DroneMap	-	-	+		+	-	$	▪▪
ArduPilot Tower	+	+	-	++	-	-	$	▪

Notes: Cost rating: $$$ = > USD 5 000; $$ = ≤ USD 5 000; $ = free.
Complexity rating: ▪ = beginner; ▪▪ = expert, good documentation; ▪▪▪ = expert.
Function: - = not applicable; + = suitable; ++ = high performance.
With regard to ArduPilot, there are two distinct products from the same company used at different steps.

The United Nations University, through the University of Twente's Faculty of Geo-Information Science and Earth Observation, has used lightweight drones to map structural damage following disasters (University of Twente, 2017). The

BOX 5

Drones for disaster risk reduction in the agriculture sector

In a bid to stay ahead of the negative impacts of climate change, floods and typhoons on food security, the Government of the Philippines and FAO have started using UAVs, or drones, to assess where farmlands are most at risk from natural disasters and quickly assess damage after they strike. In 2016, FAO and the Department of Agriculture in the Philippines co-funded the procurement of drones as well as the training of technical experts to enhance pre- and post-disaster assessments.

A fixed-wing drone is capable of mapping up to 200 hectares per 30-minute flight with a ground resolution down to 3 cm. It is equipped with a high-resolution normalized difference vegetation index (NDVI) camera, which produces vegetation index images designed for crop health monitoring. The technology will be integrated in the incoming projects on enhanced DRR tools for agriculture and fisheries.

Source: FAO (2016b, 2016c).

Photo credit: ©FAO/Jay Directo

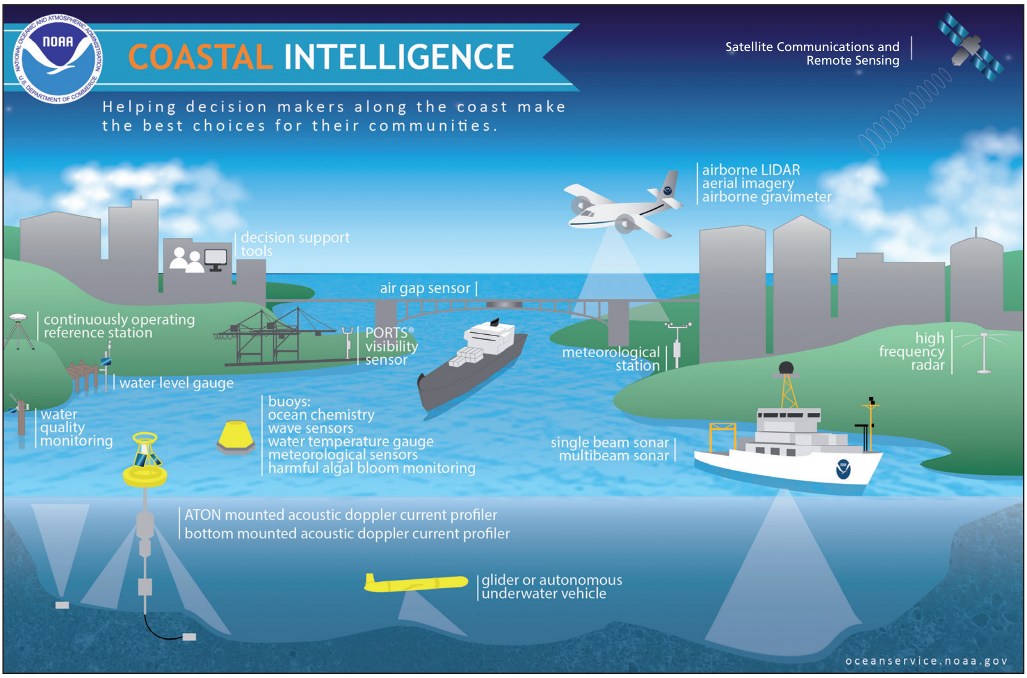
United Nations has also explored the use of UAVs for crisis management. In partnership with the European Commission, UNOSAT sponsored a technology workshop in 2013 titled "Unmanned Aerial Systems for Rapid Mapping" (Rester *et al.*, 2013). The workshop was attended by industry, academia, and protection and humanitarian groups. Five operational commercial UAV systems were employed for data collection. Post processing and final product presentation of aerial imagery was also performed to illustrate how UAV systems can be used for rapid mapping applications in the context of aid for humanitarian crisis and natural disaster relief operations. Box 5 illustrates the use of drone technology by FAO in the agriculture sector in the Philippines.

Remotely operated vehicles, autonomous underwater vehicles and underwater sensor technologies

As marine fish farm operations increase the size, capacity and complexity of cage designs, and as farming moves into dynamic offshore environments, more sophisticated technological solutions are required to provide sufficient

knowledge and information to monitor and/or control the production process (Føre *et al.*, 2017) (Figure 5). Furthermore, because of industry expansion into the open ocean, risks associated with day-to-day operations increase (Kalogerakis *et al.*, 2015).

FIGURE 5 **Underwater sensor technologies applicable to aquaculture disaster risk management**



Source: NOS (2018).

Note: Illustration of underwater sensor technologies commonly used for timely, actionable information development, so that informed decision-making can occur. For marine aquaculture, many of these sensor systems are used for the prevention of disaster-level events, and for built-in resilience.

Increased risks are created by the difficulty of accessing offshore farms to monitor stocks and cage structures. Sensors and communication systems can mitigate these risks by providing real-time data to land-based receivers, including mobile devices. At the regional scale, underwater sensor systems can collect vast amounts of data that can help predict natural disaster events (e.g. severe storms) and hazards occurring over large areas (Figure 5). At the local scale, underwater remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) (Table 13a) and underwater sensor technologies (Table 13b) combined can provide much information about cage configuration and orientation and monitor in real-time damage to culture structures, cultured organism health, and assist with farm practices (e.g. removing mortalities from cages).

Table 13a lists commonly used underwater drones applicable to aquaculture DRR according to their cost, complexity, operating time and the add-ons that increase their capabilities, while Table 13b provides a list of underwater sensor technologies.

TABLE 13a
Examples of remote and autonomous underwater sensor systems applicable to aquaculture disaster risk management

Model	Cost	Complexity rating	Operating time / Mode	# of thrusters/ vehicle type	Depth	Sensors and cameras	Image
Blue Robotics blueROV 2	$$	■■	⏲⏲⏲ - S ⏲⏲ - L ⏲⏲ - H	6 - ROV	〰〰〰	Live Low-Latency 1080p HD Video, gyroscope, accelerometer, magnetometer, internal barometer, pressure/depth & temperature sensor, current & voltage sensing, leak detection, repair kits	
Deep Trekker DTG2	$$	■■	⏲⏲⏲ - S ⏲⏲⏲- L ⏲⏲ - H	2 - ROV	〰〰〰	4k camera, real-time GPS, acoustic sensor, mortality remover, water quality sampler, sediment sampler, multibeam imager, quick change views for side by side images, temporary net repair mechanism, repair kit	
Trident	$$ (Pre-order)	■■	⏲⏲⏲ - S ⏲⏲ - L ⏲⏲ - H	2 - ROV	〰〰〰	HD Camera, GPS enabled guidance	
Power Vision PowerRay	$$	■■	⏲⏲⏲ - S ⏲⏲ - L ⏲ - H	2 - ROV	〰〰	Camera, GPS, free mode and cable, Fish finder,Bait drop, Communication cable	
Fathom ONE	$	■	⏲⏲⏲ - S ⏲ - L ⏲ - H	3 - ROV	〰〰	HD camera, modular	
JW Fishers SeaOtter-2	$$$	■■■	⏲⏲⏲ - S ⏲⏲ - L ⏲ - H	6 - ROV	〰〰〰	Sonar, magnetometer, GPS, grab arm for sampling, audio amplifier, repair kit	
AquaBotix HydroView	$$	■■	⏲⏲⏲ - S	3 - ROV	〰〰	HD camera, orientation sensor, temperature and depth sensors	
Robosea BIKI	$	■	⏲⏲⏲ - S	3 - AUV	〰〰	4k camera, camera stabilizer, gear and stock inspection	
iBubble	$$ (Pre-order)	■■	⏲⏲ - S ⏲ - L ⏲ - H	4 - ROV	〰〰〰	Camera, GPS, cable connected, diver safety during underwater work; gear inspection	
MPI Racemaker 3.0	$$$	■■	⏲⏲ - S ⏲ - L ⏲ - H	9 - RONC - ROV	〰〰〰	Dome camera; depth sensor, 3 cleaning disc with 36 nozzles for cleaning	
Flying Net Cleaner 8	$$$	■■	⏲⏲ - S ⏲ - L ⏲ - H	6 - RONC - ROV	〰〰〰	Water pressure cleaning unit, depth sensor, moisture sensor, disc speed sensors, 2 LED lights, autodepth function, fiber optic communication	

Notes:
Cost rating: $$$ = > USD 10 000; $$ = ≤ USD 5 000; $ = ≤ USD 1 000.
Complexity rating: ■ = beginner user; ■■ = expert user, good documentation; ■■■ = expert user.
Operating Mode: S – Still water; L – Low speed mode cruise; H – High Speed mode.
ROV = remotely operated vehicle; AUV = autonomous underwater vehicle; RONC = remotely operated net cleaner.
Operating time: ⏲⏲⏲ = >4 hour; ⏲⏲ = ≤ 2 hours; ⏲ = ≤ .5 hours
Depth: 〰〰〰 = >50 meters; 〰〰 = ≤ 30 meters; 〰 = ≤ 10 meters

TABLE 13b
Underwater sensor technologies, sensor implementation and the aquaculture function for these systems

Marine sensor type	Sensor implementation	Aquaculture function
Sonar	Single beam sonar	Seafloor composition; biomass depth in cage within the beam
	Split-beam sonar	Biomass depth distribution in cage Movement dynamics (position, speed) within beam
	Multibeam sonar	High-resolution seafloor data; biomass depth distribution Movement dynamics (position, speed) within entire cage volume Feed pellet detection system
Hydroacoustic	Individual fish tags	Determines depth, position, acceleration and spatial orientation of individual fish in cage
Telemetry **Passive hydroacoustic sensing**	Hydrophone	Characterization of general soundscape; Captures sound emitted from fish population
Camera	Surface camera	Surface activity of fish in cage
	Feeding camera (submerged)	Sea lice count Skin characteristics (scratches, wounds) Behavioural characteristics (e.g. systematic vs. chaotic swimming patterns, normal vs. unexpected behaviour) Species identification
	Stereo camera (submerged)	Sea lice count Skin characteristics (scratches, wounds) Behavioural characteristics (e.g. systematic vs. chaotic swimming patterns, normal vs. unexpected behaviour) Species identification Swimming speed and direction Size estimation
	Hyperspectral imager	Skin spectral characteristics
	Multispectral imager	Sea lice detection and count Detection of spectral signatures Sea lice count
Remote controlled or autonomous vehicles (ROV/AUV)	Multi-sensor systems	Gear repair; removal of mortalities from cage; general farm monitoring for repair requirements
	Ocean glider	Used to determine fish habitat and oceanographic parameters
Argo Buoy	Satellite-enabled	Temperature and salinity profiles on site
ARGOS MAR-GE T Buoy		Floatable GPS-enabled live tracking of cage position and orientation
Unmanned service vehicles	Saildrone	Long-range data collection for atmospheric, physical and ocean measurements for regional environmental characterization

Source: Adapted from Føre *et al.* (2017).

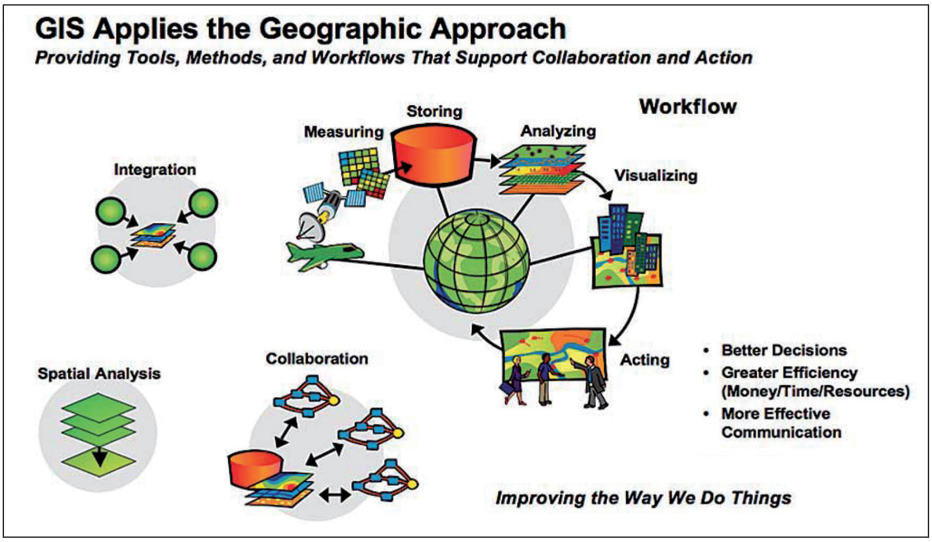
Note: This list is not exhaustive and is simply meant to illustrate some of the existing drone and sensor technologies available on the market to aid in marine data collection, maintenance and monitoring of aquaculture systems, and in disaster response and prevention.

Geographic information systems

GIS are computer-based systems for the capture, storage, management, analysis and visualization of spatial data. GIS technologies support decision-making through data organization and visualization, integration of multiple data sets for analyses, and through the creation of new data to answer questions (Meaden and Aguilar-Manjarrez, 2013).

GIS provide a powerful data management framework for large data volumes and large numbers of data sets, essential for supporting aquaculture planning and management. GIS are built around database design principles, incorporating data records (or attributes) that are connected to spatial locations. Figure 6 illustrates how GIS play an integrating role, where remote sensing or field survey data are collected, then captured, stored, analysed and visualized using a GIS to help decision-making.

FIGURE 6 **An overview of spatial technology components and approaches**



Source: Esri (2018a).

Digital capture and storage. Today, most scientific and engineering disciplines use digital data collection technology to capture information required for visualization and analysis. Cartographic products (maps and charts) are produced and distributed in digital formats. Satellite and aerial remote sensing products are digital images. GPS data and other field measurements are collected digitally. While providing considerable advantages, volumes of digital data can be enormous and data storage and archiving are critical infrastructure. Converting paper or film products to digital data is potentially time consuming and error prone, but required if data are to be accessible for DRM applications.

Many online data repositories exist, where data are usually described and categorized so the user can understand what the data set contains and represents – this information is known as "metadata". An example of a metadata discovery

system that is of use for aquaculture DRM is the United Nations Environment Programme online portal of environmental data sets (http://geodata.grid.unep.ch). Hosted data are searchable by keywords and can be filtered by thematic category, priority issue, geographic region, etc. Government agencies, United Nations agencies and other groups can assist in the capture of baseline data. A selection of spatial data portals is presented in Annex 2.

Data sharing and updating. In an emergency, data that can support emergency response should be publicly available in a timely and reliable manner. With planning, data can be prepared for web-based map viewers and accessible using a computer or mobile device without the need for specialized software. Under the Disasters Charter, international agencies make available satellite images and maps of integrated and analysed data for use in disaster situations (see section 2.4). Several web-based GIS data portals are listed in Annex 2. A specific approach to data sharing are "Story Maps", which combine authoritative maps with narrative text, images and multimedia content. Story Maps are often built using the Esri ArcGIS online platform, with numerous emergency response examples (see http://solutions.arcgis.com/emergency-management/response). The concept can also be used after an event to communicate the impacts, response and recovery efforts, for example the United Nations Institute for Training and Research (UNITAR) Story Map after the floods caused by tropical cyclone Dineo in Mozambique in 2017 (UNOSAT, 2018).

Data organization and integrity. GIS are built on database models that break data sets up into logical and interlinked components. Managing and processing GIS data typically requires specialist skills and training, but no advanced skills are needed to use data viewing applications such as Google Earth or a web-based GIS. Data viewers are useful for the communication of disaster-related information, with increasing use by the public in disaster situations.

Geospatial information management is essential for effective evidence-based, decision-making. Combining administrative and socio-economic data with hazard-related data enables modelling of risks and DRR activities. Spatial data infrastructure (SDI) is a management tool that combines data and information from a variety of sources and distributes information when and where it is most needed, which can contribute to saving lives and directing emergency operations (Box 6).

Asking questions and spatial data analysis. Well-organized spatial data can be analysed to answer important questions of varying complexity across the DRM cycle, for example:

- **DRR phase:** "Where are the fish cages that are not protected by coastal defences?"
- **Response phase:** "How many fish pond farms were affected by a flood?" or "What types of aquaculture infrastructure were damaged by a hurricane?"
- **Recovery phase:** "Which aquaculture production facilities need repair? or "What was the extent of damage to access roads associated with aquaculture following a severe storm?"

BOX 6

Spatial data infrastructure

The term spatial data infrastructure (SDI) was adopted in 1993 by the United States National Research Council to denote a framework of technologies, policies and institutional arrangements that together facilitate the creation, exchange and use of geospatial data and related information resources across an information-sharing community. SDI has a key role to play as the world becomes increasingly digital, and as societies become more information dependent. The effectiveness and efficiency of a country's SDI, in common with other major infrastructure components, will have a significant impact on its overall resilience, including the ability to develop and address a wide range of problems and development needs.

At the global level, the United Nations formed a committee of experts on Global Geospatial Information Management, in 2009, to ensure that Member States can work together, share knowledge and support the development of strong geospatial information bases. At the national level, the various legal, institutional, technological, organizational and financial issues involved in building a national SDI present a degree of complexity that requires coordination effort and funding to provide a coherent framework for data access and sharing.

Many different government institutions around the world generate large amounts of data that are not adequately used because the institutions involved lack the human capacity, technology and policies to properly process, manage and share data to inform better policy- and decision-making. In support of SDI development and use, the World Bank, with the support of FAO, is developing an SDI diagnostic tool to provide a clear picture of the status of SDI development, identification of missing components, or components that might require strengthening or further development.

Source: Tonchovska and Adlington (2011).

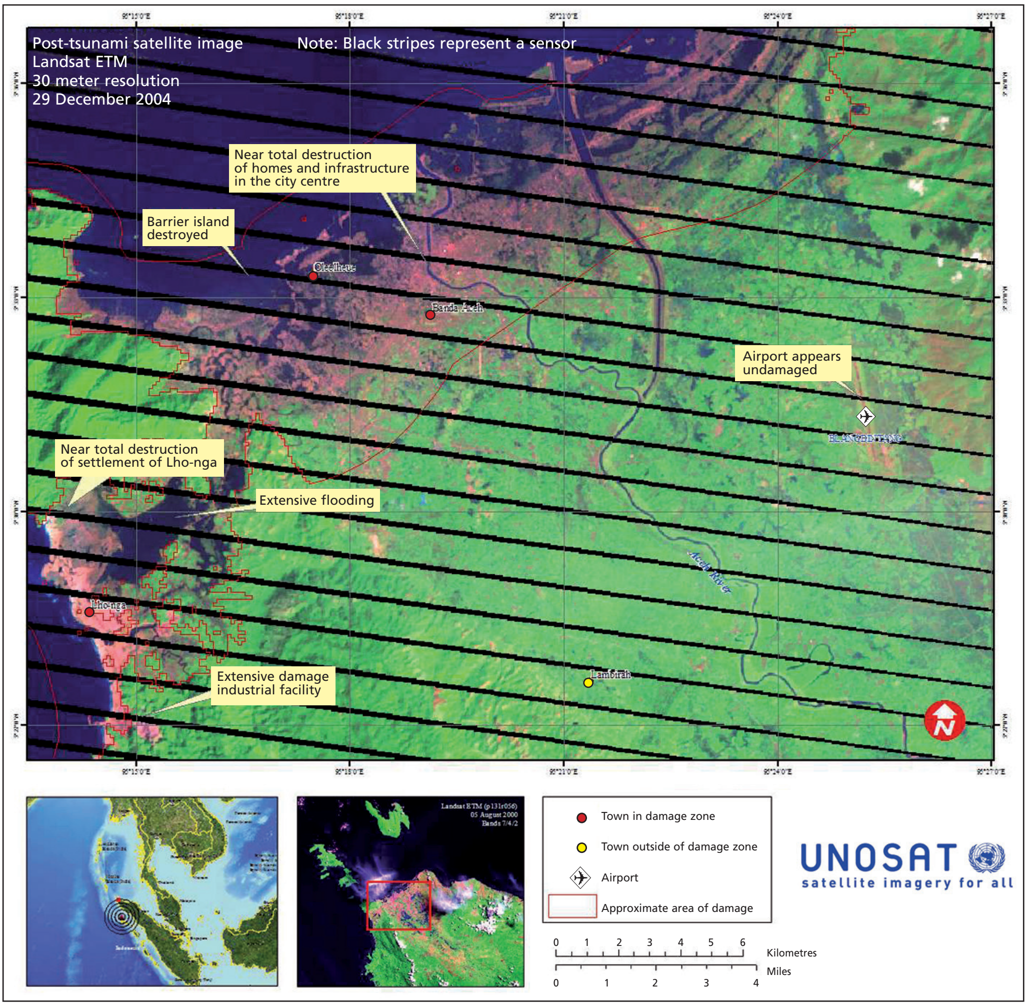
GIS software

The development of GIS for DRM by an organization is an important decision, since establishing the system, capturing and converting data, training and management are time-consuming processes. Careful planning is required to establish a GIS.

Commercial and open source GIS software and tools exist that can meet DRM needs. Some GIS-type software are specifically targeted at DRM (a selection of these systems is summarized in Table 14), which in some cases address specific types of disaster. Many "general use" GIS software can be incorporated into an organization's DRM toolkit; the most commonly used GIS software are listed in Table 15.

Many organizations publish GIS data and maps online, including FAO through its GeoNetwork open source cataloguing application for interactive maps, GIS data sets, satellite imagery and related applications (FAO, 2018c). An example of an online map from GeoNetwork of tsunami damage to Banda Aceh is shown in Figure 7. The zone of approximate tsunami damage represents areas under 20 metres in elevation and within 5 kilometres of the nearest coastline.

FIGURE 7 **Overview of tsunami damage to Banda Aceh**



Source: Modified from UNITAR (2005). *Data source:* GLCF, JPL, USGS, Global Insight.

Notes:
- Map was produced for the UNOSAT project headed by UNITAR and executed by UNOPS.
- Data source(s): USGS EROS Data Center, GL CF, JPL.
- Sensor: Landsat ETM (30 m). Image date: 29 December 2004. Map produced 1 January 2005

Publishing online maps can require specialized GIS software designed to publish data so that it may be accessed by a web service (some systems are shown in Table 14).

TABLE 14
Popular GIS-based disaster risk management software

Software package			DRM stages supported		
Name (publisher)	**Licence**	**Description**	**DRR**	**Response**	**Recovery**
CAMEO (NOAA/EPA)	Open- source	Chemical disaster data inventory and tracking	•	•	
InSTEDD (InSTEDD)	Open- source	Resource tracking and mapping, data sharing / synchronization, team coordination		•	
Ushahidi (Ushahidi)	Open- source	Cloud-based rapid crowdsourced data collection and mapping		•	
Cobra (Cobra)	Purchase	Emergency management, Hazmat, multiplatform mapping	•	•	•
CRISIS (Crisis Management Software)	Purchase	Cloud-based communication and coordination emergency response platform	•	•	
Emergeo (Emergeo)	Purchase	Fully integrated emergency response platform	•	•	•

TABLE 15
Popular general-use GIS software

Name	Publisher	Software licence/cost	Description	Complexity rating
Desktop GIS software				
QGIS	QGIS	Open source $	Desktop analysis and cartography	••
GRASS	Open Source Geospatial Foundation (OSGeo)	Open source $	Desktop analysis and visualization	••
Manifold	Manifold	Commercial $	Desktop analysis and cartography	•
IDRISI	Clark Labs	Commercial $$	Desktop analysis and cartography	•
ArcGIS	Esri	Commercial $$$	Industry standard GIS tools with additional disaster templates and disaster response information support Free ArcGIS Explorer data viewer available	••
WebGIS software				
GeoServer	Open source Geospatial Foundation (OSGeo)	Open source $	Geospatial web service (web map) provider	•••
MapServer	Open Source Geospatial Foundation (OSGeo)	Open source $	Geospatial web service (web map) provider	•••
ArcGIS Server	Esri	Purchase $$$	Geospatial web service (web map) provider	•••
ArcGIS Online and Web App Builder	Esri	Purchase $$$	Hosted online web maps and custom-made web apps	•

Notes: Cost rating: $$$ = > USD 5 000; $$ = ≤ USD 5 000; $ = free.
Complexity rating: ▪ = beginner user, training manuals; ▪▪ = expert user, good documentation; ▪▪▪ = expert user.

2.3 EMERGING INFORMATION AND COMMUNICATION TECHNOLOGIES

Advances in information and communications technologies (ICTs) are creating opportunities to improve DRM. These emerging technologies are described in the following subsections.

Addressing tools

In many countries, the accuracy of addresses and/or point locations is poor, which is frustrating and can cause problems across the DRM cycle, particularly for early warning and emergency response. Ambiguity exists in street addresses postcodes; latitude and longitude coordinates are prone to transcription errors. It is estimated that around 75 percent of countries suffer from inconsistent, complicated or inadequate addressing systems. An initiative to deal with this problem is "what3words", where a unique combination of three words identifies 3 m × 3 m square areas across the entire planet (http://what3words.com). Using words means non-technical people can communicate any location accurately and more quickly. For example, a damaged port in northeast Tacloban, the Philippines, within the area "shares.project.climber" may be less prone to error than geographic coordinates.

Mobile devices and cloud-based data systems

Mobile devices are at the heart of the ICT revolution in many developing countries. Connectivity is bringing previously inaccessible information and services to remote areas and is helping to change society and economy, including in the realm of DRM. The size of personal computing devices continues to decrease, while processing systems become more powerful. These devices include cell phones, netbooks and tablet computers, which often integrate GPS and are connected to the Internet over cellular or wireless networks.

Weather forecasts and location-enabled severe weather warnings contribute to disaster preparedness. Field data collection, especially during emergency response, is greatly facilitated by agile, portable digital units. There are many systems available (see Box 7), and systems range from simple cell phone messages to sophisticated portable data collection and mapping units.

Mobile data collection tools can run as "apps" on smartphones or tablets and can be operated "live" with a real-time network connection, or in a "disconnected" mode. When offline, the operator can still make edits, take photos, collect GPS points, or fill in field data stored in the device itself. These data are then synchronized with a central system once the operator has access to an Internet connection. A demonstration smartphone field data collection form for damaged buildings, developed by Esri (2018b), is shown in Figure 8. It shows: (i) a menu to select the type of point feature to collect; (ii) the attributes to be collected for each building; (iii) the features on a thematic map backdrop; and (iv) the features on a satellite image backdrop. In the context of a disaster related to aquaculture, disaster damage assessment teams could collect local data on the status of water supply/drainage structures, harbour infrastructure and road access, etc.

BOX 7

How to choose a mobile data collection system

The NOMAD project links aid organizations with the latest information management tools to more easily collect, analyse and manage data. Since mobile phone technology, apps and geospatial technologies are rapidly evolving, the NOMAD team constantly monitors changes in the technologies and keeps the system up to date. The NOMAD project offers:

- Online Selection Assistant to connect organizations with one of 24 mobile data collection solutions (see https://humanitarian-nomad.org).
- Hands on training: NOMAD team members can train organization staff in how to use the tools and analyse the data.

Crowdsourcing

Crowdsourcing uses the skills, talents or observations of the general public, or the crowd, as sources of knowledge and expertise. The prevalence of powerful mobile communication devices and networks is an important factor in the growth of crowdsourcing in many sectors, including international development. In emergency situations, crowdsourcing describes a method of information collection that utilizes data received from volunteers to enable stakeholders to participate in disaster response through online forums, mobile devices and crisis mapping (Narvaez, 2012).

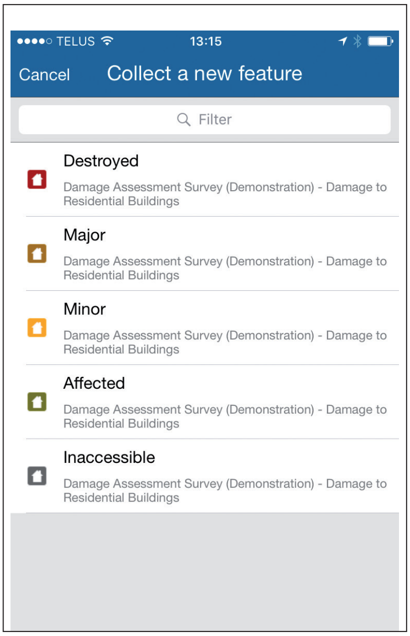
Crowdsourcing and other online participatory practices are increasingly important for emergency response. In contrast with established emergency response methods, crowdsourcing can provide fast, local information to improve situational awareness in disaster situations. Through widespread access, participation and contribution, these participatory practices also provide an open way for community members to participate in response. During Typhoon Haiyan, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), for the first time, deployed officials charged specifically with coordinating crowdsourced mapping with volunteer groups (Butler, 2013).

The Humanitarian OpenStreetMap Team (HOT) uses satellite and aerial imagery and a huge network of volunteers to create free, up to date online maps for relief organizations responding to disasters. HOT develops several open source programmes and applications to leverage collaborative mapping and the use of new technologies in the field of geographic information for humanitarian aid (HOT, 2018). Additionally, HOT participates in various long-term projects with partners, including supporting communities to build their own maps for economic development and DRR.

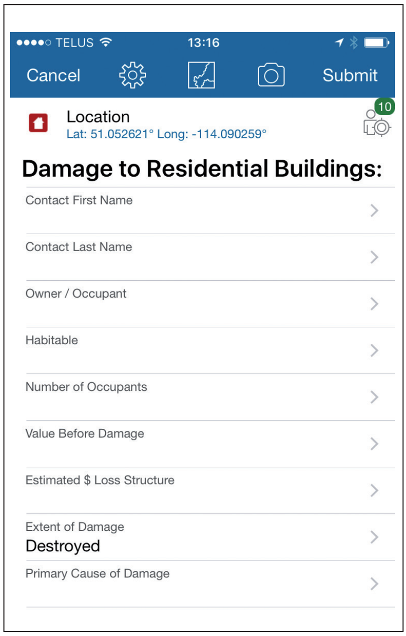
Ushahidi is a non-profit software company that develops free and open source software for information collection, visualization and interactive mapping (Ushahidi, 2018). Ushahidi offers products that enable non-experts to contribute

FIGURE 8 **Example use of Esri collector mobile app for disaster assessment**

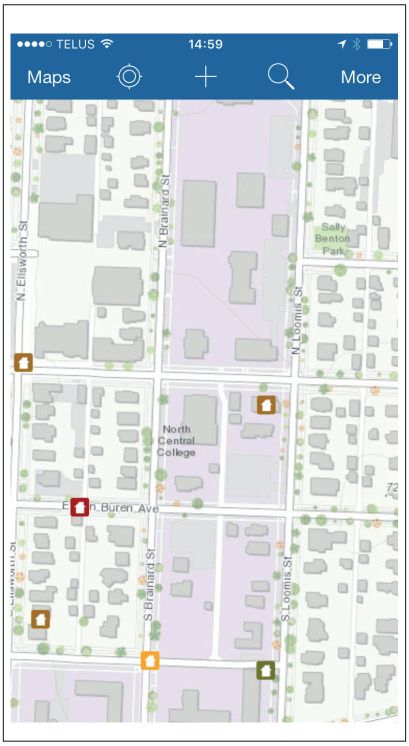
(1) Choose type of impact to collect



(2) Form to collect damage attributes



(3) Map backdrop with features



(4) Image backdrop with features

Source: Esri (2018b).

Note: This is an example of a collector form and labelling on a map that could be used anywhere in the world.

observation reports using their mobile phones or the Internet, which can be mapped. For disaster response, this ability to receive live accounts from people using cell-phone text messages or smartphones can provide a detailed view of the situation on the ground even before first responders arrive. Ushahidi has been deployed in response to earthquakes, storms and complex disasters.

Social media represent another way for the public in a disaster area to share information on their status, issues and needs. Synthesis and analysis of posts or search terms and location data can reveal patterns and trends to support disaster response.

Sensor Web and the Internet of Things

An increasingly important part of the ICT revolution, Sensor Web refers to a network of sensors linked by software and the Internet to monitor the environment. Sensors are connected via telemetry, an automated communications process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment for monitoring. Sensor Web devices are considered part of the Internet of Things.[4] For example, the National Aeronautics and Space Administration (NASA) has established a volcano Sensor Web with *in situ* sensors that can trigger an autonomous satellite observation response. This "system of systems" is designed with a flexible, modular architecture to facilitate expansion in sensors, customization of trigger conditions, and customization of responses (NASA, 2018).

Advances in sensor technology and spatial positioning are leading to improvements in information available to aquaculture operators across the DRM cycle, including early warning, emergency response, and recovery and rehabilitation. Modern GPS provide accurate information about position and movements. Sensors with GPS connected by telemetry can measure a range of parameters that are useful for aquaculture. For example, sensors within a buoy or sonde can provide data on location and condition of aquaculture assets; water quality parameters such as temperature and dissolved oxygen; and current speed and wave height.

Models and simulations

Modelling is a fundamental component of many activities that are designed to improve knowledge and support decision-making throughout the DRM cycle. There are many different types and approaches to modelling, and the development or use of an existing model requires a certain level of scientific knowledge in the discipline under study. In general, modelling is a process to integrate and analyse observed data to generate outputs and visualizations that help our understanding of real world processes. Examples of models relevant to aquaculture and DRM are the following:

- weather forecasts, e.g. tropical storm strength and path prediction;
- water quality forecasts, e.g. harmful algal blooms;

[4] The Internet of Things is the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators and network connectivity which enable these objects to connect and exchange data.

- ecological carrying capacity models;
- oil spill models to forecast the fate of oil once spilled;
- flood risk models to determine the extent and frequency of floods; and
- drought risk models under current and future climate conditions.

Simulation is a broad term that can encompass a range of processes. Extreme weather is a significant risk to aquaculture systems and operations, but effective simulations allow for improved preparedness. Simulation of weather events and weather forecasting is a mature discipline that continues to improve with better models and increasing computer power. An interesting example of visualization techniques to support public interpretation of future climate change and land use choices in northeast Scotland, the United Kingdom of Great Britain and Northern Ireland, is described by Wang *et al.* (2016).

Virtual reality is a complex form of simulation and an area of active development that is crossing over from academic disciplines to use in real world applications. In a virtual reality computer-driven simulation system, the operator feels immersed in a realistic multimedia presentation. The immersive and participatory nature of virtual reality training offers a unique realistic quality that is not generally present in classroom-based or web-based training, yet retains considerable cost advantages over large-scale real-life exercises (Hsu *et al.*, 2013). Virtual reality systems offer the opportunity for first responders to gain experience that is directly applicable to real world scenarios without exposure to real world hazards.

Augmented reality, which uses the existing environment and overlays new information on top of it, is receiving considerable attention from technology companies. The potential impact of augmented reality for disaster response includes providing responders with information on pre-disaster infrastructure, population information, and simulation of potential change in conditions (e.g. flood extent).

2.4 INTERNATIONAL SATELLITE REMOTE SENSING DISASTER RISK MANAGEMENT INITIATIVES

Recognition of the potential for satellite remote sensing to support disaster response has led to regional and global initiatives to provide timely imagery and map products.

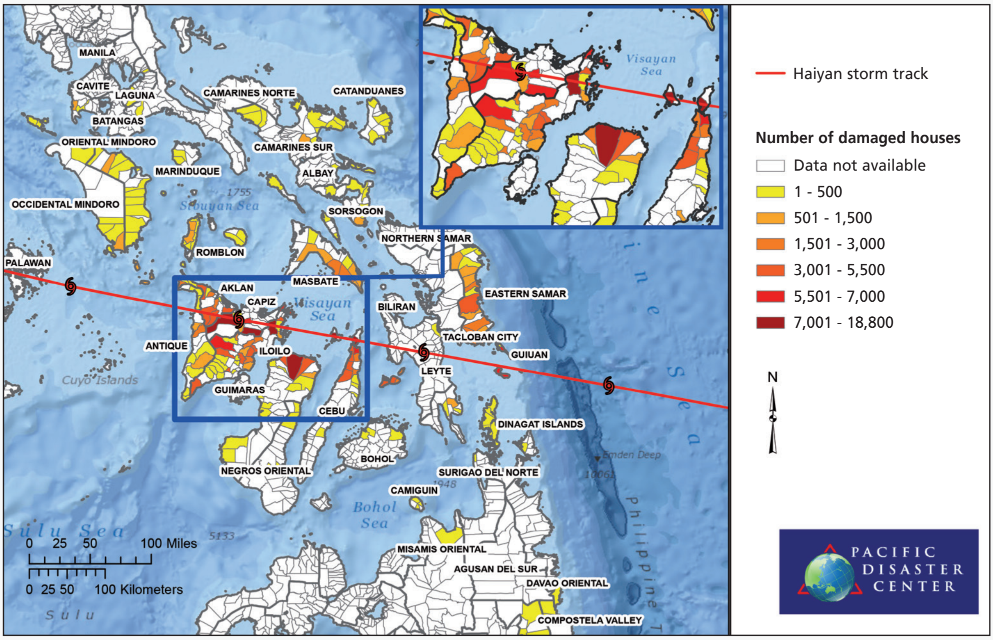
UN Resolution 61/110 (2006) established the "United Nations Platform for Space-based Information for Disaster Management and Emergency Response" (UN-SPIDER). The system, administered by the United Nations Office for Outer Space Affairs, provides remote sensing satellite-derived products designed to assist with emergency management and disaster response. UN-SPIDER also promotes awareness of space-based capabilities and makes available high-quality products to managers and operations leaders who may not have the needed capacity to create such products with their technical staff.

The International Charter Space and Major Disasters (Disasters Charter)

is a major international initiative involving international organizations and private sector satellite remote sensing system operators. The Disasters Charter aims at providing a unified system of space data acquisition and delivery to those affected by disasters through authorized users (typically a government department or agency in signatory countries). Each member agency commits resources to support the provisions of the Disasters Charter (Table 16). The Disasters Charter was declared formally operational on 1 November 2000. An example of an activation from the Disasters Charter of Typhoon Haiyan in the Philippines is illustrated in Box 8.

BOX 8

Major disasters caused by Typhoon Haiyan in the Philippines



Super Typhoon Haiyan (known locally as Yolanda) made landfall over the central Philippines at 04:40, local time, on 8 November 2013. The category 5 storm brought winds as strong as 314 km/h and analysts believe it may be one of the strongest storms to make landfall in recorded history.

The storm left widespread damage in its wake across the central Philippines, with power lines cut off and roads blocked by fallen debris and trees. Buildings were flattened under the strong winds, with wooden houses particularly susceptible to the storm. Haiyan also caused a storm surge which brought waves crashing down onto coastal areas, and the damage from the storm surge was more extensive than that of the winds.

Source: Modified from International Charter Space and Major Disasters (2018). Pacific Disaster Center.

Notes:
- Data source(s): Esri, NOAA, NDRRMC
- This map depicts the number of houses destroyed or partially damaged by Typhoon Haiyan (Yolanda). This map is based on information from NDRRMC Situation Report #20, 15NOV13, 0600 PHT. Only data for those municipalities who have reported is shown.
- The delineation of political boundaries, and associated data shown

TABLE 16

Major international and regional geospatial disaster support initiatives

Initiative	DRM stages			Description
	Disaster risk reduction	Response	Recovery	
Disasters Charter (ESA, CNES, CSA, private sector, and UN bodies)		•		Members commit resources to provide satellite-derived disaster information to Charter members. Service is free and international in scope. Activation is by authorized users from charter members. https://www.disasterscharter.org
Copernicus Emergency Mapping Service (EU)	•	•	•	Service is free and focused on Europe and areas of European interest. Activation is by authorized users. http://emergency.copernicus.eu
Sentinel Asia (JAXA)	•	•		Service, covering the Asia-Pacific region, is available primarily to Asian Disaster Reduction Center member organizations by request. https://sentinel.tksc.jaxa.jp/sentinel2/topControl.jsp
SERVIR (USAID, NASA)	•	•	•	Products are free for approved projects, with international scope. Satellite-derived products focus on environmental monitoring, including near real-time. https://www.servirglobal.net
UNOSAT (UNITAR)		•	•	Provides timely products to United Nations decision-makers, non-governmental organizations and others integrating satellite imagery, GIS and field data. Topical areas of focus include crisis and situational mapping, damage and impact assessment, safety and security, and capacity building. Products are free and international in scope. www.unitar.org/unosat
MapAction		•		Non-governmental organization providing in situ geospatial information collected by disaster response volunteers. Products are free and international in scope. www.mapaction.org

Source: Adapted from UN-SPIDER (2017).

3

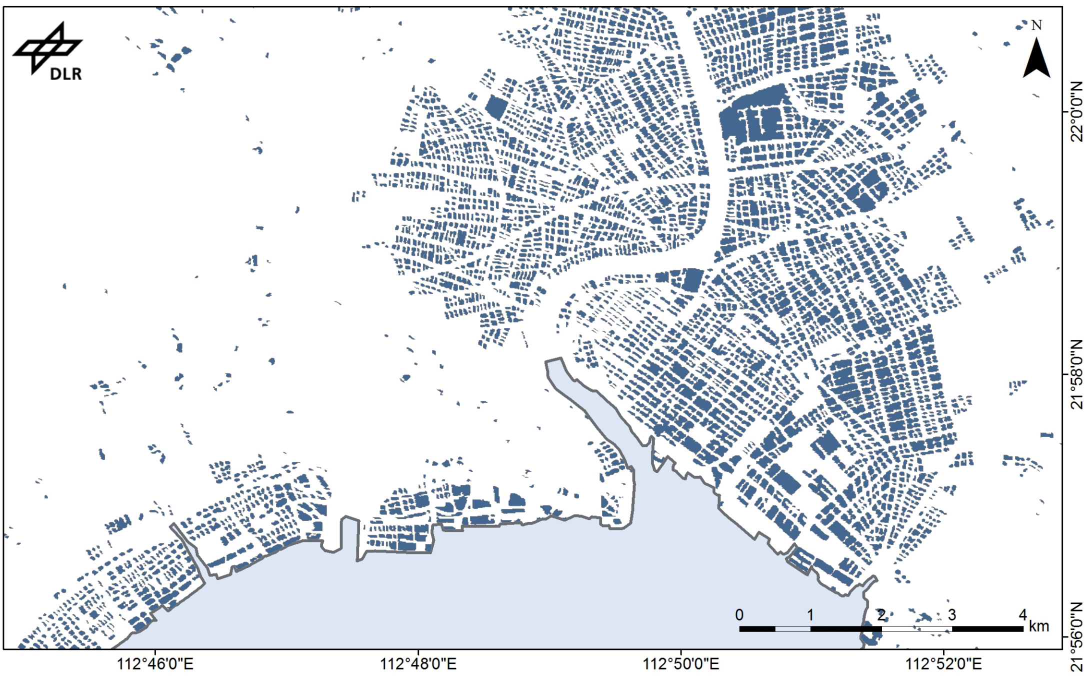
How to use spatial technologies for disaster risk management

Spatial technology can be applied across the DRM cycle and for the different types of disaster. The following sections provide an overview of how to use spatial technologies within specific stages of DRM.

Main challenges to the implementation of spatial technology by aquaculture managers include:

- understanding which spatial technology and remote sensing data source is most relevant to address the problem;
- knowing where to find the data that are needed;
- being able to access, process, analyse and interpret the information; and
- having rules and regulations to support and implement spatial management decisions.

The following sections provide an overview of how to use spatial technologies within specific DRM phases. Various spatial technology training resources that complement the information in this section are described in Annex 3.



Aquaculture pond detection in the Pearl River Delta, China

Satellite remote sensing allows for the detection and monitoring of aquaculture ponds, thereby improving the effectiveness of spatial planning and management interventions that reduce risks.

The all-weather, day and night imaging capabilities of radar satellites are particularly well-suited to cloud-prone coastal regions. The approach used to derive images of the aquaculture ponds shown here is transferable in time and space and therefore holds potential for continental or global mapping.

Source: Ottinger, Clauss and Kuenzer (2017; 2018).

Data source: Sentinel-1 radar image (top); mapped aquaculture ponds (bottom).

Courtesy of German Aerospace Center (DLR) and German Remote Sensing Data Center (DFD).

3.1 DISASTER RISK REDUCTION: PREVENTION, IMPACT MITIGATION AND PREPAREDNESS

DRR includes a range of activities, including prevention, impact mitigation and preparedness. DRR spatial technology checklist is shown in Table 17, with the following sections providing more details.

TABLE 17
DRR checklist: how to use spatial technology for prevention, impact mitigation and preparedness

Disaster risk tasks	Spatial data and tools
1. Define ecosystem and political boundaries and develop a baseline	
• Use spatial information to capture environmental, socio-economic baseline data and administrative data. • Use remote sensing (satellite images or aerial photos) to create up to date baseline maps of land cover, coastal habitats, land/ocean use, and oceanographic or hydrological baseline conditions for aquaculture farming areas. • Mapping aquaculture facilities to improve the effectiveness of planning and management interventions to risks. • Integrate the data in a GIS and make maps accessible for free to different stakeholders, e.g. using a Web GIS, PDF maps or hard copy maps. Ensure the data are well documented (e.g. with metadata).	• **GIS** to integrate available baseline environmental, social and economic data into a common framework for analysis. • **Crowdsourcing** to capture spatial baseline data (e.g. roads and infrastructure data collected by OpenStreetMap). • **Buoys and other aquatic sensors** to continuously measure primary environmental parameters. • **Satellite remote sensing or aerial survey** as input to map land cover, coastal habitats, and land/ ocean use in aquaculture production areas. • **Satellite, aerial or drone surveys** to map aquaculture structures. • **GPS or mobile devices** to map aquaculture structures. • **GIS** to support communication through baseline maps.
2. Conduct an aquaculture disaster risk assessment	
• Use the baseline GIS data to review current activities and risks in inland and coastal areas. • Identify areas and processes that are more exposed to serious disasters and potential impacts on aquaculture operations and livelihoods, e.g. ponds not protected by mangrove habitats or onshore production in earthquake-prone areas. • Analyse the data to model and map the most suitable areas for aquaculture.	• **GIS** to integrate available data for risk analysis. • **Models, simulations and forecasts** to assess risk. • **Exclusion and suitability analyses** to determine best areas for aquaculture.
3. Develop and test a preparedness plan and early warning systems	
• Ensure access to and monitoring of available early warning information (e.g. weather, algal blooms). • Create simulations and plans for specific types of emergencies.	• **GIS** to prepare response and evacuation maps. • **Models and simulations** to test response and refine plans. • **Response training** simulations.
4. Review policy considerations for disaster risk reduction	
• Review policy considerations for disaster risk reduction	• **GIS** to produce maps in support of policy formulation and decisions.
5. Review aquaculture insurance requirements	
• Review aquaculture insurance requirements.	• **GIS** to produce maps in support of insurance applications. • **GIS** to assess relative risk by insurance companies.

Define ecosystem and political boundaries and develop a baseline

As part of regional planning, aquaculture managers should review and define the ecosystem boundaries of their operations area and develop an environmental and socio-economic baseline. Ecosystem boundaries can be based on geophysical, physico-chemical, biological and ecological characteristics (e.g. a hydrological catchment). Socio-economic and administrative boundaries demarcate the management area. Correspondence between ecosystem boundaries and management areas provides more effective planning structures. However, these boundaries seldom coincide and mapping of areas of correspondence and gaps is needed.

Use spatial information to capture environmental and socio-economic baseline data and administrative data

The first step is to identify the important baseline data for understanding risks, planning response, and assessing change, loss and extent of damaged infrastructure following a disaster. Baseline information is designed to provide a good picture of "normal" aquaculture operations in areas at risk from hazards (Brown and Poulain, 2013).

Collecting, updating and analysing baseline information is an integral part of disaster preparedness. It is preferable, and far more effective, to prepare baseline information before a disaster. The picture of a pre-disaster situation is fundamentally important in the process of assessing damage and emergency response needs and should be completed and maintained as part of a nation's disaster preparedness strategy. In poor, disaster-prone regions, external funding helps to ensure the completion of appropriate baseline data collection.

An aquaculture baseline is intended to meet the following objectives (Brown and Poulain, 2013):

- facilitate the comparison of aquaculture activities and outcomes for families, communities and local economies before and after a disaster;
- provide a robust basis for making estimates of the impact of disasters on aquaculture, which can feed into flash appeals (United Nations coordinated humanitarian response);
- give a "head start" to and provide a basis for immediate post-disaster assessments, including the initial impact appraisal; and
- provide a basis for the more in-depth detailed sector assessment.

Spatial technology is essential to providing high-quality, informative baseline data. Remote sensing provides input for up to date land cover, coastal habitats and land/ocean use in aquaculture production areas. GIS are used to integrate data, including new data with existing sources of baseline data (e.g. administrative boundaries, port locations, road networks). Online sources of spatial data for baseline development are provided in Annex 2.

Use remote sensing (satellite images or aerial photos) to create up to date baseline maps of land cover, coastal habitats, land/ocean use, and oceanographic or hydrological baseline conditions for aquaculture farming areas

Often, available baseline data are out of date, or the available data do not provide sufficient quality information to support risk assessment and DRR activities. Remote sensing (satellite images and aerial photos) can fill data gaps in existing baseline information to update maps for aquaculture farming areas. The potential to use remote sensing data to create thematic baseline data such as roads and coastal infrastructure, aquaculture facilities, habitat and water quality is summarized in Table 18.

TABLE 18
Capability of remote sensing to provide baseline data

Required thematic data set	Capability of satellite remote sensing
Roads, coastline, river or lake edges, etc.	**High** – identify and manually digitize road networks and other feature boundaries. Typically requires optical satellite or aerial images with 5 m spatial resolution or better.
Coastal infrastructure (e.g. communities, ports, facilities, other industries)	**High** – identify and classify land use through manual digitizing or semi-automated image classification using remote sensing software. Typically conducted using optical, aerial or satellite images with 30 m spatial resolution or better.
Distribution of aquaculture	**High** – identify and classify aquaculture through manual digitizing or semi-automated image classification using remote sensing software. Typically requires optical or radar aerial or satellite images with 10 m spatial resolution or better.
Vegetation/habitat extent and condition (e.g. mangroves, seagrass)	**High** – identify and classify habitat through manual digitizing or semi-automated image classification using remote sensing software. Typically conducted using optical images with 30 m spatial resolution or better, with radar images providing useful information for specific habitats such as mangroves.
Water availability	**Medium** – identify and map the extent of surface waterbodies such as lakes. Semi-automated image classification using remote sensing software. Monitoring is possible through regular processing of images. Typically conducted using optical or radar satellite images with 10 m spatial resolution or better. Limitations exist for small waterbodies, or waterbodies that are deep where surface area is not a good indicator of water availability.
Water quality (productivity and turbidity)	**Medium** – processing of optical satellite imagery to estimate chlorophyll-a and total suspended solids concentration. Typically conducted using optical images with 10 to 500 m spatial resolution. Requires in situ measurements for calibration. Daily observations are only possible with coarse resolution input data sets.
Water depth (bathymetry)	**Medium** – processing of optical satellite imagery to estimate bathymetry in shallow coastal areas or lakes. Requires optical clear water conditions. Typically conducted using optical satellite images with 1 to 30 m spatial resolution. Maximum depth estimate approximately 35 m, with accuracies within 10 percent of actual depth +/- 0.5 m (EOMAP, 2018).
Topography (elevation, slope)	**Aerial: High** – stereo aerial photography and airborne LiDAR provide the most accurate elevation data with vertical accuracy possible to 1 cm and spatial accuracy typically one to three times the spatial resolution. Ground control data are needed. **Satellite: Medium** – stereo satellite images can be used to extract elevation, with spatial resolution of 2 m and vertical accuracy close to 50 cm. Ground control data needed for highest accuracy.

Required thematic data set	Capability of satellite remote sensing
Water temperature	**Medium** – water temperature such as sea surface temperature routinely obtained from optical satellites with thermal sensors. Typically coarse resolution such as 1 km resolution.
Water currents and roughness	**Medium** – surface currents and wave height estimated from radar satellites, but with coarse spatial resolution (e.g. 4 km) and not in coastal and estuarine areas.

Note: Capability ratings based on the authors' expert judgement with reference to the World Meteorological Organization and its Observing Systems Capability Analysis and Review (OSCAR) tool (see Annex 2).

Mapping aquaculture facilities to improve the effectiveness of planning and management interventions to mitigate risks

Inventories and monitoring of aquaculture facilities provide decision-makers with important baseline data and trends on production, area boundaries, size distribution of farms, environmental conditions and impacts, spatial risks to the ecosystem and farming systems, and other information. Mapping facilities improves the effectiveness of planning and management interventions to increase production, improve emergency preparedness (including for disease outbreaks) and reduce risks.

Remote sensing can be used to map aquaculture facilities frequently (i.e. weekly to annually) and at required spatial resolution (see section 2.2), which can complement *in situ* observations to support aquaculture management.

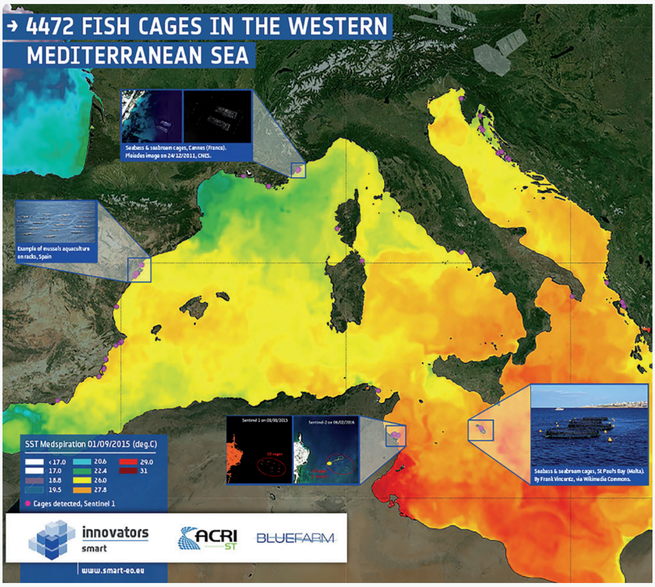
FAO assists countries to record the locations and types of aquaculture structures so that countries can improve their aquaculture zoning, site selection and area management. The work of FAO by Travaglia, Kapetsky and Profeti (1999) and Travaglia *et al.* (2004) demonstrated the mapping of coastal aquaculture and fisheries structures using radar satellite images in Sri Lanka and the Philippines.

Aquaculture structures and their evolution can be assessed against locations of sensitive ecosystems and habitats to highlight potential impacts, as well as to assess spatial risks to aquaculture. Structures can also be linked to the licencing process to identify unregistered or illegal facilities and land tenure issues. FAO's National Aquaculture Sector Overview (NASO) map collection provides a spatial inventory of aquaculture with attributes, including species, culture systems and production (FAO, 2018d). Based on Google Earth/Maps technology, the NASO map collection assists and encourages countries to develop inventories as part of their strategic planning for sustainable aquaculture development. Google Earth is a good starting point for spatial inventories of aquaculture, as it provides high-resolution images available for free and does not require remote sensing expertise (Trujillo, Piroddi and Jacquet, 2012).

Advanced approaches based on image analysis require the use of GIS or remote sensing software and access to satellite images in their original format. Box 9 provides an example of the use of remote sensing for conducting an aquaculture inventory in the Mediterranean Sea, as demonstrated by the European Space Agency (ESA).

BOX 9

Satellite imagery for fish cage inventory in the Mediterranean



Images from the Sentinel-1A satellite are being used to monitor aquaculture in the Mediterranean in another example of ESAs contribution to food security. Over six months, Sentinel-1A image analysis detected nearly 4 500 aquaculture structures, mainly of mussel racks or finfish cages along the western Mediterranean's coastline. The number of fish cages and mussel racks in the Mediterranean was unknown before this survey. Remote sensing of oceans is a window into the marine ecosystem, providing essential information for their governance. Analysis of data from satellites can provide essential information to evaluate site locations, monitor aquaculture facilities and meteorological events, provide early warnings and track water pollution.

Source: ESA (2016).

More recently, Ottinger, Clauss and Kuenzer (2017) of the German Aerospace Center (DLR) developed a novel approach to assessing coastal aquaculture at large spatial scales by using earth observation time series. They analysed large volumes of free and open Sentinel-1 radar data to derive and map aquaculture ponds for four study sites in the major river deltas of China and Viet Nam. They further developed their approach to allow for the estimation of aquaculture production using data derived from Sentinel-1 observations (Ottinger, Clauss and Kuenzer, 2018).

Integrate data in a GIS and make maps accessible, easily and at no cost to different stakeholders

The outputs of baseline development should include maps with delineation of important administrative boundaries, risk of disasters, and geographic location of aquaculture structures (Brown and Poulain, 2013).

The checklist in Table 17 recommends that GIS should be used to integrate different types of data and to make maps accessible for free to different stakeholders, e.g. using a Web GIS, PDF maps or hard copy maps. It is also important to ensure the data are well documented with metadata.

Conduct aquaculture disaster risk assessment

Use baseline GIS data to review current activities and risks in inland and coastal areas

A broad range of hazards can impact aquaculture farming areas, which, broadly speaking, can be grouped as follows: environment, biosecurity, climate-related risks, social conflicts and governance. The baseline data collected in step 1 of the checklist in Table 17 provides important data needed to identify risks. The objective of this step is to identify areas that are more exposed to disasters and quantify/evaluate potential impacts on aquaculture operations and livelihoods.

Aquaculture produces outputs such as food, jobs and income, but also has potential negative ecosystem impacts such as nutrients or chemicals. Potential impacts need to be identified within a specific scale and ecosystem boundary so that risks can be defined as local, regional or national. Transboundary issues should also be addressed, where applicable, for example river systems can transport nutrients and waste from aquaculture production across borders into another country or region.

Aquaculture is vulnerable to several catastrophic climatic hazards and other disturbances. Climate change and urban pollution impacts on aquatic environments invariably have damaging effects on aquaculture. Natural and biological risks such as hurricanes and disease outbreaks apply to specific production systems and locations.

Identify areas and processes that are more exposed to serious disasters and potential impacts on aquaculture operations and livelihoods

The objective of this step is to identify areas and aquaculture production processes (e.g. upstream seed and feed supply and downstream post-harvest aspects) that are most exposed to serious disasters and to prioritize the most important risks that should be addressed through management measures. Understanding and applying risk analysis in aquaculture needs to consider the diverse nature of aquaculture (in terms of species, environments, systems and practices) and the range of hazards. FAO has produced a manual on the application of risk analysis to aquaculture (Bondad-Reantaso, Arthur and Subasinghe, 2008), which discusses risk sectors and provides recommendations to enhance the application of the risk analysis process to aquaculture production.

Most of the major threats to aquaculture have a spatial dimension and can be mapped. Risk mapping of aquaculture farming areas should include risks associated with the clustering of several farms in the same water resource – for example, consideration of the 100-year flood extent, historic wave height, or maximum high water to determine areas susceptible to flooding. Box 10 provides a summary of the World Risk Index.

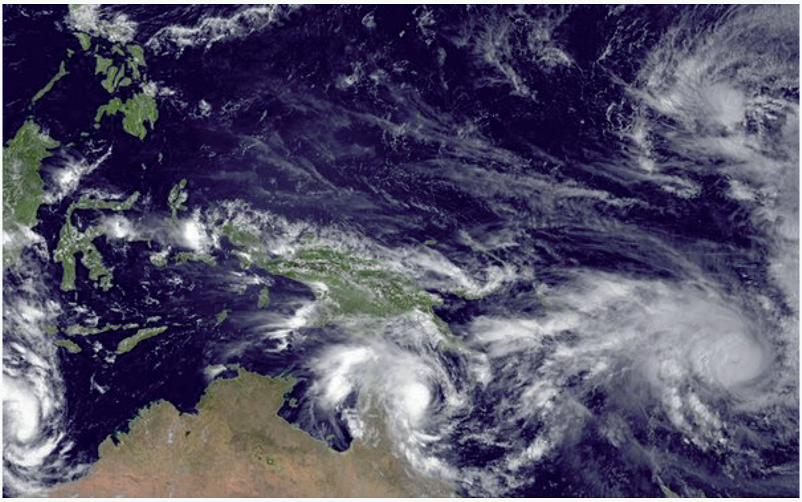
Risk mapping can help to identify the most important threats. Annex 4 describes two examples of risk mapping for Bangladesh: the first describes the use of satellite remote sensing data to monitor surface water distribution and flooding; the second uses a climate model data and GIS to assess the spatial distribution of risk of drought and temperature extremes under current and future climate conditions.

BOX 10

The World Risk Index

The World Risk Index reveals which countries are most at risk from rising sea levels and increasing frequency of floods, droughts and severe storms.

Countries are ranked using the World Risk Index, which takes into account the frequency of natural disasters in each country (known as exposure) and how well equipped the country is to cope with and recover from the effects of a disaster. The index integrates many factors, analysing data on public infrastructure, housing quality, medical services, education level and more.



Cyclones and tropical storms head for landfall in the Pacific Ocean, 11 March 2015.

Source: Bündnis Entwicklung Hilft and United Nations University, 2016.

Photograph: United States National Oceanic and Atmospheric Administration.

Examples of risk maps for aquaculture planning and management include:

- Islands and wave strength. Pérez, Telfer and Ross (2003) produced climate-related wave risk maps for offshore cage culture site selection in Tenerife, Canary Islands.
- Floods and aquaculture. Modelling the flood cycle, aquaculture development potential and risk using MODIS data: a case study for the floodplain of the Rio Paraná, Argentina (Handisyde *et al.*, 2014).
- Monitoring algal bloom development. Environmental information system using remote sensing data and modelling to provide advanced warning of potentially harmful algal blooms in Chile so that their impacts can be minimized by the aquaculture industry (Stockwell *et al.*, 2006).

The examples above and other examples can be found at:

- The GISFish Global Gateway to Geographic Information Systems, Remote Sensing and Mapping for Fisheries and Aquaculture (FAO, 2018e) (www.fao.org/fishery/gisfish/index.jsp).

- GIS and spatial analysis. GIS and remote sensing journal articles from the Institute of Aquaculture, University of Stirling (2018) (www.aqua.stir.ac.uk/GISAP/gis-group).

It is also important to assess the environmental and socio-economic risks that aquaculture can pose to other sectors and on itself. These may include biodiversity losses due to organic and chemical pollution, diseases generated by fish farms, and impacts from escaped fish. These risks are evaluated and mitigated by effective management – guided by consideration of the carrying capacity – of a zone or site location (Ross *et al*., 2013; Aguilar-Manjarrez, Soto and Brummet, 2017; TAPAS, 2018). For large industrial farms (e.g. salmon cages), models are used to estimate the spatial distribution of specific parameters to evaluate risks. For example, NewDEPOMOD – the latest version of DEPOMOD – is used to estimate organic matter and to assess the deposition and biological effects of waste solids from marine cage farms in Scotland, the United Kingdom of Great Britain and Northern Ireland (Scottish Association for Marine Science, 2016). DEPOMOD is used for planning and monitoring by the Scottish Environment Protection Agency, and is also increasingly being used at the international level by countries such as Canada, New Zealand, the United States of America and several Mediterranean countries. The Norwegian "MOM" method involves modelling to optimize the set-up of the number and size of cages, taking into consideration factors affecting fish welfare and environmental conditions, such as disease transmission and particle transport (Ancylus, 2018).

Analyse the data to model and map the most suitable areas for aquaculture

Using the baseline data and assessment of exposure to disaster risk, GIS can be used to support aquaculture zoning, site selection and area management (FAO and World Bank, 2015). The selection of the spatial area designated for aquaculture development and careful evaluation of farm sites are important to ensure the success and sustainability of aquaculture. They should be carried out in accordance with the Code of Conduct for Responsible Fisheries (FAO, 2011) and the ecosystem approach to aquaculture (FAO, 2010).

Aquaculture zone allocation, site selection and management areas should include the evaluation of disaster risk. This requires a range of different spatial data and information, including social, economic, environmental and governance-related data. Spatial technology provides the best means to integrate such data to conduct spatial analysis for zonation and risk reduction.

Develop and test a disaster preparedness plan and early warning systems

Ensure access to and monitoring of available early warning information

A preparedness plan should define the use of technology and procedures for data processing before and during an emergency so that accurate and timely information such as reports and maps can be made available. Disaster preparedness maps, such as planned zones for restricted movements and/or closure of harvests, should be developed in advance.

Preparedness means having spatial technology in place for rapid response to events and the capability to muster the resources to apply the technology, including leadership, communications and coordination. Plans and preparations should be based on realistic disaster scenarios, which provide a surrogate for real disaster events.

Early warning systems are part of disaster preparedness since these systems can provide advance notice and enable mitigating actions. To set up an early warning system, links with government agencies and centres that provide early warning data are required.

Weather forecasts are a common early warning system and are generally provided as a public good by government. Numerical weather models provide predictions of general weather, tropical cyclones, hurricanes, wildfire risk, wave height, extreme winds, rain and other phenomena. Some areas have tsunami early warning systems. Such concepts can be extended for aquaculture, and companies and governments may obtain water quality forecasts related to parameters such as temperature or algal blooms (Box 11). Major operational weather and ocean information sources are provided in Annex 2.

Create simulations and plans for specific types of emergencies

Simulations are one component of the emergency preparedness and early warning. By integrating knowledge of past events and the hazards involved, simulations can assist with questions about potential impacts and the effectiveness of response interventions.

Simulations can include mapping of evacuation routes and locations to move assets to safety. For example, following the 2004 Indian Ocean tsunami, efforts have been made in Indonesia to determine evacuation routes from coastal locations. In vulnerable areas, multi-storey tsunami shelters were developed.

Biological disasters such as HABs are an important concern for aquaculture. Many commercial aquaculture facilities plan for such disasters, which can include the locations where assets can be relocated and the process of moving assets given sufficient advance warning via forecasting tools.

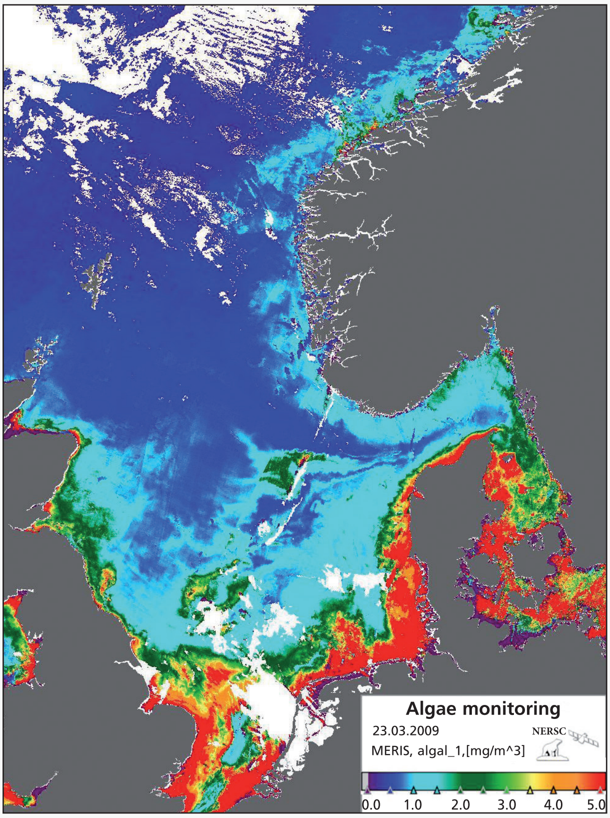
Review policy considerations for disaster risk reduction

An important component of the checklist for prevention, preparedness, mitigation and early warning is to ensure a review and update of policies related to aquaculture management, which involves managing the use of inland and coastal areas to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics. Well-designed management policies can guide zoning of land use and coastal activities, aquaculture site selection, and disaster preparedness to avoid or greatly reduce risks.

Coastal zoning can delineate areas for coastal environmental protection, different types of development and recreation use. Aquaculture zoning and site selection policies require planning based on environmental data, socio-economic data and disaster risk considerations. For example, a carrying

BOX 11

Harmful algal blooms - early warning for aquaculture



Harmful algal blooms (HABs) are periodic explosions of certain species of microscopic algae, often close to the coast where nutrients are generally higher from anthropogenic inputs. HABs are associated with toxicity in shellfish as well as large-scale fish die-offs – both of which result in major economic losses. Two to three days' warning of an impending HAB could have a major benefit for affected farms.

The European Union-funded Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms (ASIMUTH) (Maguire *et al.*, 2016) project used various data sources to produce a HAB forecasting tool for aquaculture. Researchers used a collection of satellite and modelling data to construct a HAB forecasting tool. They incorporated ocean, geophysical, biological and toxicity data to build a near real-time warning system. This comprises a web portal, an SMS alert system for farmers and a smartphone app. The web portal is curated and maintained by scientists in each country participating in ASIMUTH (France, Ireland, Portugal, United Kingdom of Great Britain and Northern Ireland, and Spain).

Source: NERSC/ESA.

capacity study can help determine the appropriate density of marine cage culture operations and sites. Evaluation of exposure to potential hazards is an integral element of disaster risk reduction. The power and benefit of spatial technology for policies related to DRR is illustrated by the integration of diverse and complex information and the clear presentation of the information in map and numerical format.

The results of studies and disaster risk assessments can inform policy decisions, as in the development of infrastructure such as a "coastal shield",

which can dissipate the energy of tsunami waves or high winds and act as a natural harbour for aquaculture operations.

When technological disaster impacts on aquaculture operations and livelihoods occur, policy should ensure that compensation by the polluter is made to safeguard aquaculture operations. Fines and other penalties should be transparent and payments should be rapid so as to protect livelihoods.

Review aquaculture insurance requirements

Aquaculture insurance is an important component of risk management strategies for many commercial aquaculture operations. Therefore, as part of the DRR for preparedness and early warning checklist (Table 17), a review of insurance requirements is recommended. Aquaculture insurance includes various types of insurance cover to protect aquaculture business operations. For large aquaculture enterprises, this could include a wide-range of insurance against perils that cause loss of stock and damages to farm equipment and other farm assets (van Anrooy *et al.*, 2006). For small and medium farms, however, the availability of insurance is limited, particularly for farms located in vulnerable areas which are prone to natural disaster risks; if insurance is available for them, it is often provided by state-owned insurance companies (see Box 12).

BOX 12

Insurance and the 2004 Indian Ocean tsunami

The tsunami that devastated Southeast Asia in late 2004 demonstrates the extensive damage that can be caused by a single event. Aquaculture sites over thousands of miles of coastline were affected, from Indonesia, Myanmar, Thailand, southern India, Sri Lanka, the many islands in the region, and across to the coast of Kenya. Many shrimp farms were affected, but the disaster would have been proportionately greater if the aquaculture infrastructure was more extensively developed. No insurance company can afford to ignore what happened in 2004; the event has made aquaculture much more difficult to insure. Much of the industry is concentrated along coastlines, long sections of which are exposed to major storms, plankton blooms and tsunamis. The 2004 event probably reduced the availability of aquaculture insurance coverage over a wide area.

Source: Secretan *et al.* (2007).

The supply side of the aquaculture insurance market includes main players such as insurers and reinsurers (reinsuring is a method insurance companies use to spread or transfer the risks). A few large reinsurance institutions, such as GE Insurance Solutions, Lloyd's of London, Munich Re, and Swiss Re dominate the international aquaculture insurance market.

Initially, aquaculture insurance was hampered by a lack of reliable data and underwriting experience. Insurance companies now use spatial technologies and tools (e.g. visualization through GIS, spatial analysis using commercial or proprietary custom applications) to better manage risk (e.g. from risk prediction to claims management). Based on experience gained from past disaster events, insurance companies have enabled larger scale aquaculture facilities to be better prepared for severe storms and other natural hazards through improvements in farming equipment. For example, Munich Re provides its NATHAN Risk Suite to assess the risks of natural hazards around the world, from the location-based individual risk through the entire risk portfolio (Munich Re, 2017).

Munich Re (2011) reports that aquaculture insurance "catastrophe cover" (i.e., disaster-level) for major losses involves substantial deductibles. It insures against the effects of large storms, algal blooms or major viruses that affect 20 percent or more of the fish stock. Aquaculture insurance applications are expected to include detailed maps of facilities and the production site, including the location of the farm, current speed and direction, storm exposure and recent history of extreme meteorological conditions.

It is acknowledged that only 3 percent of farms worldwide are insured (i.e. insurance is inaccessible or not obtained for 97 percent of farms); it is mostly large farms that have access and can afford to buy insurance. Since more than 80 percent of aquaculture production is from small to medium scale facilities in Asia, there is likely to be major potential for insurance businesses to expand to new markets and to develop new product lines. Indeed, China and Viet Nam recently piloted aquaculture insurance programmes under social protection policies (Nguyen and Pongthanapanich, 2016; Xinhua *et al.,* 2017). These programmes targeted small- to medium-scale farmers who are regionally the major producers and who are most vulnerable to climate-related risks, i.e. disease outbreaks plus natural events and disasters that can cause substantial loss of stock and damage to farm assets. Insurance can help relieve the burden on governments of direct financial assistance in emergency and rehabilitation programmes. However, experience from the pilot programmes suggest that the design of insurance programmes needs to be tailored for the unique characteristics and needs of small aquaculture enterprises.

Insurance can be bundled with credit. It can be used as an incentive for farmers to adopt climate-smart and good aquaculture practices, all of which require active involvement from other players in the commodity cluster and throughout the value chain. Institutional mechanisms, such as mutual organizations and cooperatives, have been used to facilitate the implementation of an insurance scheme for small farmers. Parallel investments, in the form of a reliable and robust information system for early warning, surveillance and monitoring, and damage assessment are absolutely necessary. The training of key personnel for managing and implementing the entire insurance system and the supporting services should be part of the investments (FAO, 2017).

An example of the imagery used to assess damage to the aquaculture sector in Aceh Province, Indonesia, following the 2004 tsunami

A massive tsunami devastated the coastline of Banda Aceh, Indonesia, on 26 December 2004. The spatial extent of the damage caused to coastal aquaculture ponds along the coast of Aceh Province may be seen in these satellite images taken before and after the disaster and acquired under the Disasters Charter.

Data source: IKONOS 1 m.

Courtesy of DigitalGlobe.

3.2 EMERGENCY RESPONSE: DAMAGE AND NEEDS ASSESSMENT

Following a disaster event, a needs assessment is undertaken to inform the emergency response. If DRR is effective, good baseline information would be available, as well as emergency response plans, contingency plans and preparedness activities. Timeliness, reliability and quality of information about the disaster and the impacted or potentially impacted assets is essential for emergency response. Spatial technology, especially satellite and aerial remote sensing, is an important source of such information.

The spatial technology DRR checklist in Table 19 and the following subsections provide more details on how to use spatial technology for emergency response. The tasks described for emergency response would be supported by comprehensive preparedness and early warning (see Table 17).

TABLE 19
DRR checklist: how to use spatial technology for emergency response

Emergency response tasks	Spatial data and tools
1. Planning damage and humanitarian needs assessments	
• Select the appropriate damage assessment methods, depending on the type of disaster and a review of data and tools available from preparedness planning	• **Satellite remote sensing** to determine the extent of the disaster (e.g. Disasters Charter products) • **Aerial surveys** to determine the extent of the disaster • **GIS** to enable impact appraisal, data analysis and cost calculation focused on the aquaculture sector
2. Initial impact and needs assessment to inform the response	
• Review international response and assessment data and products, e.g. Disasters Charter • Conduct aerial or ground surveys of disaster impacts to complement available satellite image products • Conduct initial impact appraisal based on available data	• **Aerial surveys** or **drone surveys** to support impact and needs assessment • **GPS** and **mobile devices** to support data collection for impact and needs assessment • **Crowdsourcing** to contribute data for impact or needs assessment • **GIS** to integrate available data for assessment
3. Data analysis and summary to assess damage	
• Integrate satellite, aerial and ground damage assessment into a GIS • Conduct rapid GIS analysis and produce clear damage and needs map products	• **GIS** to analyse data and produce impact and needs assessment maps
4. Damage evaluation and calculation	
• Continue to update the data on damage and needs as data are produced • Assess damage effects along the aquaculture value chain • Revise response plans in coordination with agencies	• **GIS** to support damage calculation • **Remote sensing** to continue to update information

Planning damage and humanitarian needs assessments

Select the appropriate damage and loss assessment methods, depending on the type of disaster and a review of data and tools available from preparedness planning

Most disasters are unexpected and sudden, which results in immediate challenges for those responding to them as they try to understand the damage and loss caused and the needs of those affected. Advance specifications for damage and needs assessment help to ensure that appropriate damage assessment methods are used according to the type of disaster.

Assessments guide effective decision-making with regard to response (relief and rehabilitation). Damage and needs assessments are spatial assessments, given that they address questions such as "What is the extent of the disaster?", "Where are the affected people and infrastructure?", and "How is the affected area accessible"?

Post-disaster baseline surveys and needs assessments should be completed quickly after a disaster and include the extent to which the policy framework and management capacity are suitable for supporting an effective emergency response (Cattermoul, Brown and Poulain, 2014).

Key challenges for damage and needs assessment include the following:

(i) Adverse weather may prevail following certain types of disasters, with cloud cover potentially affecting satellite image acquisition and aerial surveys.
(ii) Extent of disaster impacts can be large, including long linear features such as complex coastlines.
(iii) Varied impact of disaster, depending on vulnerability, infrastructure distribution and exposure.
(iv) Disaster situations evolve following an initial survey to inform disaster response (relief) activities; detailed surveys would support the design of disaster rehabilitation.
(v) Ground access can be difficult or hazardous.
(vi) Impacts occur along the aquaculture value chain, meaning that the whole "value chain" needs to be understood and assessed for the impacts inflicted on the chain. The typical aquaculture value chain includes input supply, production, processing, transport and sale to the consumer.

A holistic response to a disaster requires an assessment and understanding of the entire process including hatchery, production, and transferring fish from the point of production to the point of consumption. Additionally, complex relationships linking together diverse actors and agencies found along this chain must be understood.

An early priority for emergency response is understanding the extent and nature of the impacts from a disaster and the needs of the impacted community. This typically begins with an initial damage and needs assessment survey leading to the design of disaster response (relief) activities. Following initial relief efforts, a detailed survey for the design of disaster rehabilitation

programmes may be conducted. These surveys can best be supported by spatial technology. The approach and selection of spatial technology should be informed by disaster preparedness actions (section 3.1). A typical approach for damage assessment includes:

(i) Compile initial reports regarding the extent and magnitude of an event.
(ii) Review damage assessment products available from international organizations (e.g. following activation of the Disasters Charter). Satellite imagery can provide a rapid and systematic overview of an affected area; imagery from optical and radar satellites will be rapidly available if a disaster was large enough to trigger the Disasters Charter.
(iii) Conduct aerial surveys, based on disaster response specifications and protocols. An aerial survey often includes observations made by aircraft crew. Increasingly, drones are used, especially in small areas.
(iv) Integrate satellite maps and aerial surveys within GIS-enabled impact appraisal, data analysis and cost calculation focused on the aquaculture sector.
(v) Conduct ongoing monitoring, depending on the nature of the disaster, e.g. monitoring the rise and recession of flood waters or movement of an oil spill.

Initial impact and needs assessment to inform the response

Review international response and assessment data and products

A government or company responding to a disaster should review emergency response maps, images and data provided by regional and global disaster response initiatives (described in section 2.4). Using these products, which are often available very quickly following a disaster, can avoid duplication of effort. While the damage assessment maps are not specific to the aquaculture sector, many can support initial damage assessment for aquaculture. An example of satellite imagery for damage assessment following Typhoon Haiyan in the Philippines is shown in Figure 9.

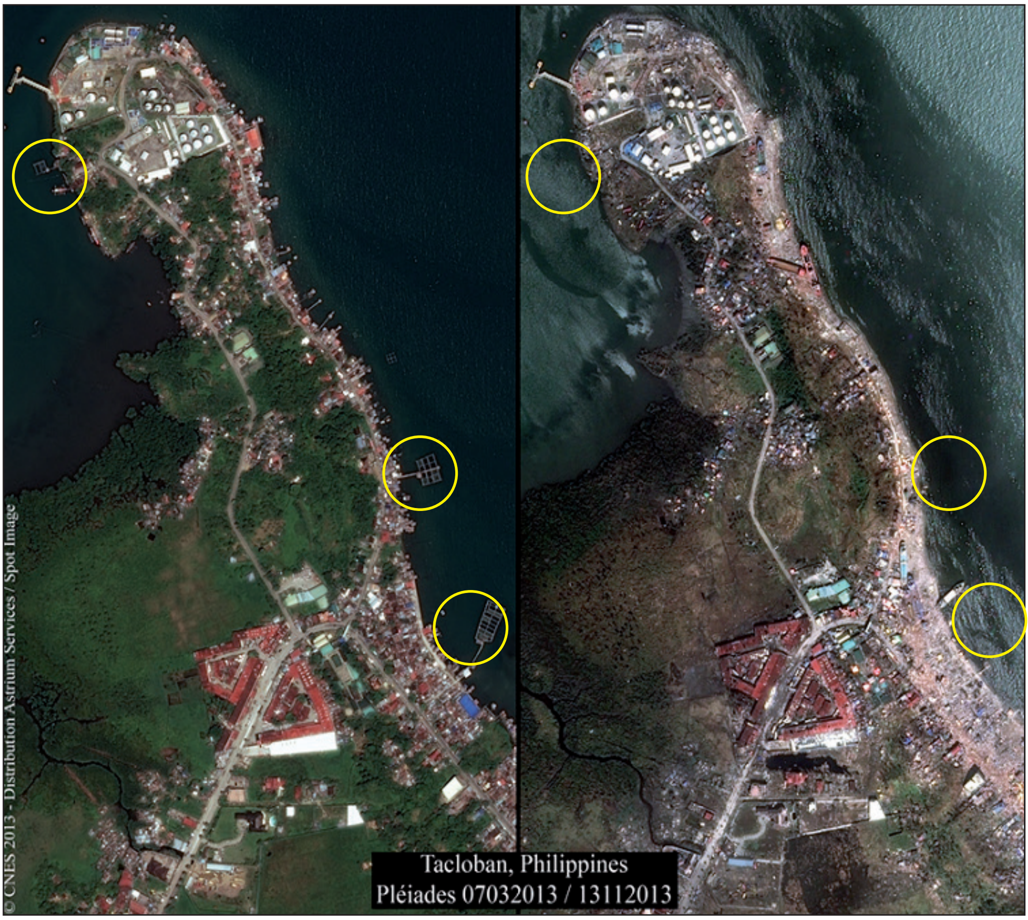
Conduct aerial or ground surveys of disaster impacts to complement available satellite image products

To complement and enhance the satellite image products from the international response, ground-based or aerial surveys (using aircraft or drones) are usually required. Effective disaster preparedness would mean that aerial survey and data collection procedures would be available (see aerial survey in section 2.2). Spatial technology described in section 2 can provide quality data for impact and needs assessment.

Conduct initial impact appraisal based on available data

Planning an effective response relies on a rapid initial impact appraisal, which provides an immediate summary of the impacts of a disaster on the aquaculture sector and other relevant sectors. Box 13 illustrates the damage and needs assessment of the aquaculture sector in Indonesia following the 2004 Indian Ocean tsunami. Mapping and remote sensing were supporting tools for the assessment (Phillips and Budhiman, 2005).

FIGURE 9 **Example of imagery for damage assessment of Typhoon Haiyan in Tacloban, the Philippines, before and after the event**



Source: UNOSAT (2013).

Note: Marine fish cages (inside yellow circles) shown along the coastline before (7/3/2013) and after the event (13/11/2013).

Data analysis and summary to assess damage

Integrate satellite, aerial and ground damage assessment into a GIS

Following the initial impact and needs assessment, more detailed analysis of damage to aquaculture and other infrastructure such as transportation networks and utilities is needed. Satellite images, drone images and field surveys provide valuable information, but integration using a GIS allows for a more comprehensive analysis. Using a GIS, a range of data can be integrated, including satellite imagery, ground survey locations captured using GPS, and baseline data sets.

Conduct rapid GIS analysis and produce clear damage and needs map products

Using before and after satellite imagery, supplemented with on-the-ground or aerial survey data collection, damage and needs maps can be generated.

BOX 13

Damage and needs assessment of the aquaculture sector in Aceh Province, Indonesia, following the 2004 tsunami

Damage assessment showed at least 20 000 hectares of aquaculture ponds were damaged, with another 5 000 hectares out of production due to damaged water supplies. A significant source of income and employment for the province was lost, with at least 40 000 people employed in aquaculture directly affected. Knock-on effects were felt on households dependent on aquaculture. For example, public services lost staff and facilities, severely affecting their capacity to support rehabilitation.

Aquaculture was effectively stopped in the major farming areas of the east coast (of Sumatra) and disappeared from the severely impacted west coast. The main causes of damage were debris and silt causing sedimentation in ponds and irrigation canals. The damage to brackish-water irrigation canals disrupted water supplies, which in turn stopped farming in other areas. Extensive damage occurred to 193 of the 223 shrimp hatcheries. There were losses of marine fish cages in Simeulue and Nias islands.

Source: Brown *et al.* (2010).

Symbolization of the level of damage using damage assessment maps can support effective communication of impacts. The Disasters Charter website provides good examples of disaster damage maps; one example is presented in Box 14 for Typhoon Haiyan in the Philippines.

Damage evaluation and calculation

Continue to update the data on damage and needs as data are produced

As disaster response unfolds, it is important that data on damage and needs continue to be captured, updated and maintained. Under the Disasters Charter, the international community captures and analyses remote sensing images as needed. As described in section 2.3, satellite images analysis through crowdsourcing is increasingly used in the days and weeks following a disaster to compile damage data.

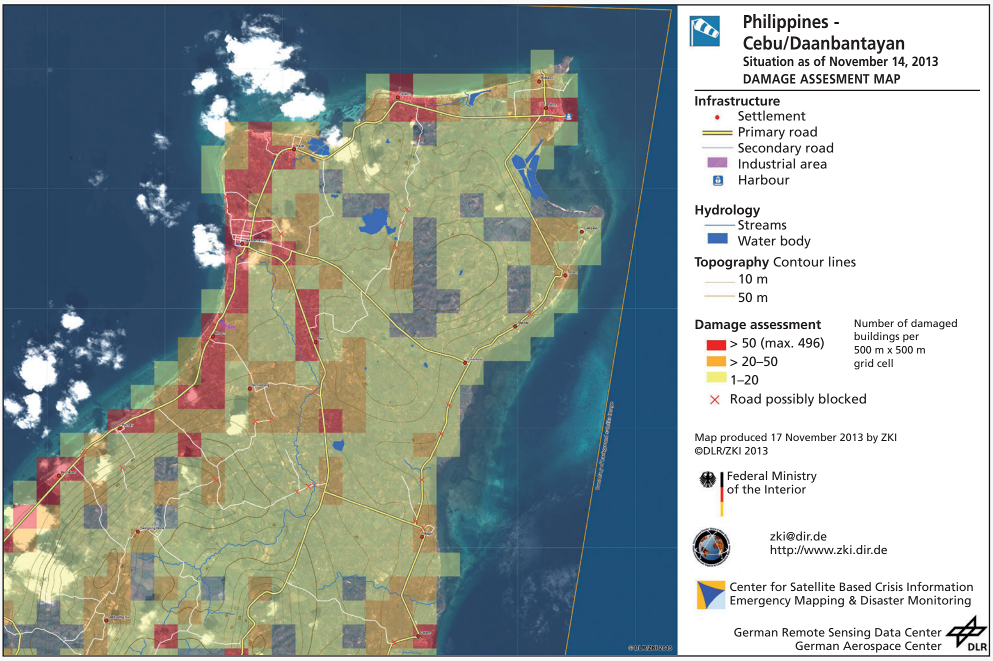
The initial reliance on satellite images and aerial assessment may shift to ground-based assessment over time as agencies mobilize resources. A field survey supported by spatial technology such as GPS-enabled mobile devices can capture data that can be easily integrated into GIS for data analysis, as discussed in section 2.3.

Assess damage effects along the aquaculture value chain

Availability of fish and fish products should be included in post-disaster food supply assessments and the resumption of fish production given priority in areas where fish is an important part of the diet and livelihood of communities. Relevant fisheries/aquaculture experts – local and international, as required – should advise or ideally be included in damage assessment teams (Westlund *et al.*, 2007).

BOX 14

Damage assessment map of Typhoon Haiyan in Tacloban, the Philippines



On 8 November 2013, Typhoon Haiyan made landfall in the Philippines, triggering a massive 5 m storm surge and adversely impacting coastal communities. A detailed damage assessment was completed using visual interpretation of post-event Pléidaes satellite data. Counts of damaged buildings were aggregated on a 500 m × 500 m grid. Red squares indicate > 50 (max. 496) number of damaged buildings. The map is a result of shared mapping efforts among emergency response teams.

Source: Modified from International Charter Space and Major Disasters. 2018. Typhoon Haiyan in the Philippines [online]. Germany [Cited 8 October 2018]. www.disasterscharter.org/web/guest/-/typhoon-haiyan-in-the-philippin-5

Data source(s): Pléiades (0.5m) © CNES 2013, Distribution Astrium. Services / SPOT Image S.A.
Vector data © DLR/ZKI 2013 © OpenStreetMap contributions 2013 © USGS 2000

Disaster impact and needs maps are a good starting point to assess how a disaster has impacted the aquaculture value chain. Cattermoul, Brown and Poulain (2014) suggest that assessment should include the following:

- Critical interlinkages between aquaculture operations and communities – spatial technology (e.g. crowdsourcing, remote sensing) can support understanding of the status of roads, ports, feed barges, transport vessels and processing facilities.

- Asset value – spatial technology (e.g. remote sensing) can support value calculations, for example by identifying the type and number of production facilities that were damaged.
- Most at risk or vulnerable operations – spatial technology (e.g. crowdsourcing, remote sensing) can help to identify assets having the highest risk, for example closest to a disaster event or those cut off from the value chain.
- Habitat and stock sensitivity – spatial technology can reveal where habitats have been most adversely affected and prioritize rehabilitation based on need.

Disaster cost calculations are important to quantify the financial requirement for economic recovery and reconstruction and to define government priorities for intervention.

The Global Facility for Disaster Reduction and Recovery publishes damage, loss and needs assessment (DaLa) guidance notes (GFDRR, 2017). The DaLa methodology is based on a stock-flow model that measures damage to assets and changes or losses in economic flows. It applies a "bottom up" approach through sector-by-sector assessment of disaster effects to aggregate standardized sectoral results to establish the overall disaster effects. In the aquaculture sector, FAO has published the Guidance note on post disaster damage, loss and needs assessment in agriculture (FAO, 2012), which includes fisheries and aquaculture.

Revise response plans in coordination with agencies

As an emergency unfolds, it is important that response plans and the associated data are regularly reviewed and updated in coordination with other agencies. This process will be supported by an effective data and information sharing plan, which can include maps and spatial technologies such as WebGIS, described in section 2.2. In most of the disaster scenarios considered, the impact on aquaculture will only be a component of a wider disaster relief effort – so the tools used in specialist aquaculture assessments will need to be well integrated within the system used by disaster relief team leaders. Much of the data required for analyses will be common to all relief causes, allowing for inputs into and prioritization of actions for aquaculture within the main system.

Net pen in the offshore waters of the Gulf of Mexico, United States of America

The risk of aquaculture gear failures associated with natural disasters changes with each location and depends on wave conditions, depth, farm design and human oversight. This net pen was deployed adjacent to an oil rig 40 km south of Pascagoula, Mississippi, in the Gulf of Mexico in 2000. The net pen was unstocked and anchored using a single point mooring configuration that broke free during a winter storm after a 50-day deployment. The cage was equipped with a GPS/ARGOS system, a satellite-based system that collects data and distributes sensor and location data to users. These systems ensure that if a net pen structure is failing, immediate action can be taken. In this case, the storm and resultant wave heights were too great to allow for the pen to be retrieved. It drifted for 40 days before washing ashore about 160 km away on the Chandeleur Islands, Louisiana. However, once the cage broke free of the mooring, the search areas required to recover it were created using ARGOS locations.

Courtesy of Mississippi–Alabama Sea Grant Consortium and the University of Southern Mississippi.

3.3 RECOVERY: REHABILITATION AND BUILDING BACK BETTER

The recovery phase follows the emergency response phase and is also supported by effective use of spatial technology, providing data and tools for planning rehabilitation and building back better. The DRR checklist in Table 20 outlines how to apply spatial data and tools for rehabilitation and building back better, with details in the following subsections.

TABLE 20
DRR checklist: how to use spatial technology for rehabilitation and building back better

Tasks	Spatial data and tools
1. Identification of the main issues and factors that may facilitate or obstruct recovery and rehabilitation, or make people vulnerable to shocks	
• Review the main issues and then select the core data sets to support multidisciplinary recovery efforts • Conduct a gap analysis – which data sets are missing or need to be updated	• Review and conduct a gap analysis of the data sets acquired during the response phase from remote sensing (satellite, aerial and drone), crowdsourcing, and GPS and mobile surveys
2. Review practice and legislation	
• Review current best practices and legislation regarding data sharing and access to spatial data	• All spatial technologies to be considered under the scope of the review
3. Facilitate damage and loss data collection, analysis and field verification	
• Consolidate geospatial data sets that capture pre-disaster conditions and damage assessment, i.e. from activities completed during preparedness (see Table 17) and emergency response (see Table 19) • Work with experts on restoration or rehabilitation plans across sectors, especially sectors that affect aquaculture production	• Pre-disaster data sets from all spatial technology sources • Post-disaster expert assessment supported by GPS and mobile devices, drone surveys, and aerial and satellite remote sensing
4. Build upon baseline and emergency response data to support the restoration of production capacity	
• Maintain and update spatial data sets and products as rehabilitation gets under way	• GIS, modelling and simulation analyses

Identification of the main issues and factors that may facilitate or obstruct recovery and rehabilitation, or make people vulnerable to shocks

Understanding the complexity of people's livelihoods, including the factors that caused peoples' vulnerability to a disaster, is key to the implementation of the principle of building back better, which includes: better preparedness; better adaptive capacity; and better resilience.

There is increasing recognition that emergency response should focus not just on saving human lives, but also on protecting and strengthening livelihoods and ensuring that people, communities and nations are more

resilient in the face of future shocks and longer-term processes of change. This approach to emergency response has been endorsed by the United Nations General Assembly and articulated by the evaluation of the response to the 2004 Indian Ocean tsunami disaster in terms of building back better (Telford, Cosgrave and Houghton, 2006). In the post-disaster recovery, rehabilitation and reconstruction phase, building back better reduces vulnerability to future disasters and increases public education and awareness of disaster risk. Building back better is also one of the guiding principles of the Sendai Framework for Disaster Risk Reduction (see Box 1).

The recovery stage involves implementation of a restoration plan that follows a building back better approach. Such an approach recognizes that aquaculture facilities and processes may have needed repairs, updates or replacements prior to a disaster. Recovery efforts can thus result in a more resilient aquaculture sector compared with what was in place before the disaster. Government compensation schemes and commercial insurance enable recovery, while rehabilitation programmes, usually of governments and often with donor assistance, enable building back better.

Review the main issues and then select the core data sets to support multidisciplinary recovery efforts

The first part of the rehabilitation and building back better checklist (Table 20) is identification of the main recovery issues. Recovery planning is a multidisciplinary effort, which includes integrated planning across several sectors. Within the aquaculture sector, planning rehabilitation and identification of key issues will include updated environmental and socioeconomic data sets. For example, relief efforts following a severe coastal storm may focus on the immediate impact of flooding, affected communities and impacted infrastructure. Recovery planning following the recession of the flood needs information such as the new position of coastline or rivers, changes in coastal habitats, infrastructure damage and community vulnerability.

Spatial technology such as GIS can help multidisciplinary experts to conduct integrated disaster recovery planning and develop priorities. For example, an integrated approach may identify infrastructure such as water treatment and supply systems as priorities because communities and industries depend on them, including aquaculture.

Conduct a gap analysis – which data sets are missing or need to be updated

Disaster response often produces large amounts of data that can be directly used in building back better planning. Along with the baseline data collected before the disaster, these data sets should meet the needs of restoration and rehabilitation planners. However, a gap analysis can help identify if data are missing specifically related to the aquaculture sector. Subsequently, specific studies or surveys may be needed to inform the planning process.

Review practice and legislation

Review current best practices and legislation regarding data sharing and access to spatial data

Increased availability and utilization of spatial information in recent disaster events has encouraged development of best practices, as well as attempts to pass legislation to ensure sharing and access of needed spatial data to all parties.

International legislation includes the Disasters Charter, which ensures that remote sensing data are available to support emergency response and recovery. The Disasters Charter ensures that predefined "authorized users", who are typically disaster management authorities from Charter member countries, can activate the Charter. There is no limit on the length of time that a Charter member can continue to request post-disaster images under the Charter, but images are typically acquired in the first few weeks of the emergency relief period.

At the national or regional level, legislation may require governments to have an emergency response plan. The aquaculture sector should be included in plans when aquaculture production systems and supply chains form an important component of local and regional economies.

Facilitate damage and loss data collection, analysis and field verification

Consolidate geospatial data sets that capture pre-disaster conditions and damage assessment

Disaster preparedness efforts to compile baseline spatial data sets and emergency response should generate a large amount of spatial data that can support recovery planning and implementation (e.g. culture facility location, supporting infrastructure, environmental parameters and critical inputs). To support recovery, these data sets should be consolidated and analysed (Table 20). Multidisciplinary disaster recovery planning will identify additional data collection, analysis, and field verification that may be needed to address the main rehabilitation issues.

Data collection may use any of the spatial technologies identified in this guide, depending on the requirements of planners and needs of the community. It is important to consider the "best" method to collect the needed data, which could include satellite imagery, aerial surveys, drones or field surveys using GPS and mobile spatial data collection devices. For example, if planners identified a need to know the extent and condition of 20 km of coastal mangroves, satellite imagery will be the best method. If planners want to know the number of culture structures[5] and facilities requiring repair, field data collection is needed and should include records of culture structure and facilities condition, repair requirements, and the owner of the operation.

5 There are many different types of structures that house an aquaculture facility. The type of structure chosen depends on several factors, some of which include: type of species to be raised, climate of area, location of site, available funding for a structure, and size of the operation.

Work with experts on restoration or rehabilitation plans across sectors, especially sectors that affect aquaculture production

Multisector cooperation, data sharing and integration of planning efforts are required to build back a community better than before. Spatial technology can be a positive force to support these efforts. The approach for restoration or rehabilitation is similar for all sectors, and aquaculture experts should coordinate with other sectors, especially regarding issues such as water quality and supply, road and port infrastructure, and energy supply.

Build upon baseline and emergency response data to support the restoration of production capacity

Maintain and update spatial data sets and products as rehabilitation gets under way

The goal of this phase of DRM is restoration of production capacity. It also offers the opportunity to infuse resilience[6] within the aquaculture production units and the management area. As rehabilitation is implemented, some spatial data sets will be updated using a range of technologies, such as GIS, mobile devices and remote sensing (e.g. see Table 18 on the capability of remote sensing to provide baseline data).

The immediate priority of recovery assistance is to enable the farmers whose farms were damaged to resume production as quickly as possible. The restoration plan aims to rebuild, repair or replace with better technology in the design and construction of damaged culture facilities. Recovery should identify facilities such as water intake systems that are required to support all farms, ensure that the response is timely, and consider the seasonality of production cycles, as well as the capacity to deliver technical assistance and inputs.

Spatial technology employed in the disaster response phase should provide information on the damage to structures and facilities. The information on the severity of damage to the different kinds of structures would guide the restoration plan (example of aerial image in Box 15). The plan crucially includes the sequence of work for restoring the function of the different structures, starting with those most critical to production. For instance, the common water supply system would be a priority for land-based aquaculture, whereas determining immediate structural damage for a cage culture system would be important in coastal areas. Information from the initial damage assessment helps inform the estimation of resources needed for restoration, and in line with the urgency given to the rebuilding or repair of each type of structure and facility, when resources should be made available and mobilized for implementation. These can be fine-tuned by subsequent ground assessments.

6 According to FAO, resilience is the ability to prevent disasters and crises as well as to anticipate, absorb, accommodate or recover from them in a timely, efficient and sustainable manner. This includes protecting, restoring and improving livelihoods systems in the face of threats that impact agriculture, nutrition, food security and food safety. In other words, resilience is the ability of people, communities or systems that are confronted by disasters or crises to withstand damage and to recover rapidly (FAO, 2018f).

BOX 15

Aerial image of a salmon farm near Tofino, British Columbia, Canada

According to the industry, salmon farms in British Columbia use newer technology to withstand strong currents and tides than the farm that collapsed in Washington State, United States of America (see Box 4).

Courtesy of B.C. Salmon Farmers Association.

Historical production data from farms would complement the information on damage to aquaculture infrastructure and support facilities and contribute to an estimate of the total value of lost production and damage.
This information is helpful in raising early and wide awareness of the loss, and in mounting a campaign to generate assistance for the restoration based on credible assessment and precise values. The technical aspects of this phase are as follows:

- The essential physical components and technical support for resumption of production are in place. These are water supply, source of seed, supply of feed, culture structures and technical services.
- Water source, supply, intake and drainage systems should be quickly repaired. Water intake, distribution, discharge systems are redesigned to improve efficiency.

- Hatchery-bred seeds are promoted for culture and sourced from reputable hatcheries. Reputable hatcheries are identified and engaged to provide the appropriate species at a desired size. If the hatcheries immediately serving the aquaculture area are partially damaged, they could be programmed for immediate rehabilitation. If the damage is severe and extensive, hatcheries from more distant areas could be contacted and sourced for seed while the nearby facilities are being repaired.
- A proper feed storage and distribution centre for the community might need to be constructed to enable large bulk purchases and quicker distribution.
- Culture facilities are rehabilitated. The farms that sustained low levels of damage are put into production as soon as possible; those that are less heavily damaged are repaired next; the ones that are seriously damaged are third in priority.
- Facilities for culture are rebuilt, repaired or replaced in a way that strengthens their resilience to future hazards. Density and spacing of cage culture units are made according to the estimated carrying capacity of the waterbody. Spatial technology can facilitate this aspect of the restoration. In a pond system, the layout of intakes and discharge channels are designed to minimize the impact of effluent discharge on receiving waters. The pond dikes can be raised and strengthened to withstand flooding.
- The farm-to-market roads, bridges, piers and landing facilities, ice plants, and market structures are next in the rehabilitation sequence to prepare for the transport of farm outputs to the market. (In any case, bridges and roads that are rendered impassable are always targeted by government for immediate repair).

Using drones to map water quality for aquaculture management in the Netherlands

The International Maritime Organization predicts a significant increase in the transport of cargo and goods by sea in the coming decades. As a result, harbours will expand and new ports will be built. Because the construction of coastal infrastructure may have an adverse impact on marine ecosystems and activities, such as coral reefs and aquaculture, remote sensing can assists both industry and governments by providing water quality maps based on satellite and drone derived imagery.

Traditional water sampling techniques are only able to cover one specific spot at a time, whereas a dredging plume can extend up to a few kilometers and constantly change over time because of the effects of currents and tides. With new drone-based technologies it is possible to monitor larger areas and estimate sediment concentrations in real-time.

This photograph shows a drone carrying a low-cost frame camera to monitor water quality in the Scheldt river (the Netherlands) in support of field staff using in situ water quality instruments.

Courtesy of Vito Remote sensing.

3.4 MONITORING AND ASSESSMENT

Monitoring and assessment should be routine components of DRM, touching all stages. Monitoring implies that baseline data are available over a suitable timeframe, involving collection of culture facility locations, supporting infrastructure, environmental parameters and critical inputs, as described in section 3.1. Emergency response will require the production of situation maps with regular updates to identify changes in conditions (e.g. structures, environment and people). The information in these maps will provide support for prioritizing response efforts and to monitor and assess the outcomes. Eventually, the recovery efforts and post-disaster conditions will require the establishment of new baselines. The DRR checklist in Table 21 outlines how to apply spatial technology for monitoring and assessment, with details in the following subsections.

TABLE 21
DRR checklist: how to use spatial technology for monitoring and assessment

Disaster risk tasks	Spatial data and tools
1. Monitoring across the disaster risk management cycle	
• Review the spatial data being collected as part of normal operations and preparedness (see Table 17)	• Remote sensing (satellite, aerial and drone) provides data in a range of themes • Sensor Web can provide monitoring data in a range of themes (e.g. water quality)
2. Monitoring and evaluation of disaster response and recovery	
• Identify the indicators to be monitored to evaluate the effectiveness of disaster response • Determine how spatial technology can support measurement of actions and results against these selected outcome indicators	• Spatial technologies depend on the indicators used for monitoring and evaluation • Remote sensing and field survey supported by mobile devices and GPS are likely technologies
3. Monitoring of climate change and other external threats	
• Identify how spatial technology can support monitoring of risks such as climate change	• Data from satellite remote sensing provides key input sources, e.g. weather satellites, storm surge and sea surface temperature

Monitoring across the disaster risk management cycle

Review the spatial data being collected as part of normal operations and preparedness

Spatial technology can support monitoring of aquaculture across all stages of DRM (as documented in Table 17, 19, and 20). The checklist in Table 21 suggests that a monitoring schedule should be defined. A monitoring schedule will be specific to each data set. For example, chlorophyll-*a* monitoring may be daily, whereas bathymetry may only need to be updated once every five years. Monitoring of sensitive habitats, such as mangroves, may be appropriate to update on an annual basis.

As explained in Table 17 in section 3.1, remote sensing has considerable potential to provide baseline data. Spatial technology can support aquaculture operators or government regulators in monitoring and maintaining regular information, including:

- location and type of aquaculture facilities;
- economic and social information, including community locations and vulnerability;
- infrastructure across the production and value chain, such as roads, ports, water supply and electricity;
- critical operating factors such as water quality and depth, and access to markets;
- environmental conditions and sensitivity; and
- emergency evacuation and response routes.

Monitoring and evaluation of disaster response and recovery

Identify the indicators to be monitored to evaluate the effectiveness of disaster response

Governments and international organizations involved in disaster response and recovery need to know the effectiveness and impact of their efforts. Such information can point to improvements in future disaster relief and rehabilitation efforts. Monitoring and evaluation promotes learning and performance measurement.

The United Nations Development Programme has published the Handbook on planning, monitoring and evaluating for development results (UNDP, 2009), which seeks to address planning, monitoring and evaluation:

- **Planning** ensures that programmes and projects have a greater chance of success when the objectives and scope of the programmes or projects are properly defined and clarified. This reduces the likelihood of experiencing major challenges in implementation.
- **Monitoring** can be defined as a continuing function that aims primarily to provide the management and main stakeholders of an ongoing intervention with early indications of progress, or lack thereof, in the achievement of results. An ongoing intervention might be a programme, project or other kind of support to an outcome.
- **Evaluation** is a selective exercise that attempts to systematically and objectively assess progress towards, and the achievement of, an outcome. Evaluation is not a one-time event, but an exercise involving a full range of assessments of differing scope and depth carried out at several points in time in response to evolving needs for evaluative knowledge and learning during the effort to achieve an outcome. All evaluations – even project evaluations that assess relevance, performance and other criteria – need to be linked to outcomes as opposed to only implementation or immediate outputs.

To conduct effective outcome monitoring, managers need to establish baseline data, select outcome indicators of performance, and design processes

and procedures. Under the supervision of a manager, technical personnel would establish baseline data, select outcome indicators of performance, and design mechanisms for systematic data capture, analysis and reporting.

Monitoring can include farmers or farm clusters through a periodic reporting scheme to capture the technical and economic performance of the farms. Training in record-keeping may be required, which could enable simple cost and return analysis of either the aggregate results or the results of a sample of farms. This can provide an objective basis for improvements and, should the results be encouraging, persuasive evidence for farmers to continue adopting best management practices and improving their technical efficiency, and inform donors and government of the impact of the intervention.

Determine how spatial technology can support measurement of actions and results against these selected outcome indicators

Spatial technology such as satellite remote sensing can be a useful data source for cost-effective monitoring and evaluation, but this is often overlooked in the design of monitoring and evaluation indicators. Table 22 provides some examples of the potential role of spatial technology in supporting the monitoring of indicators. While not replacing on-the-ground assessment of the complex range of factors that contribute to disaster recovery and resilience, spatial technology should form an important part of monitoring and evaluation.

Examples of indicators of sustainable small-scale aquaculture development, their measures, and possible data sources are defined by Bueno (2009).

TABLE 22
Examples of monitoring and evaluation indicators and the role of spatial technology

DRM outcome	Example role of spatial technology		
	Indicator	Data sources	Method
Restoration of market access for aquaculture products	• ength of roads restored and repaved • Number of bridges rebuilt	• Aerial remote sensing • Field survey	• Image interpretation • GIS mapping of roads and bridge conditions
Improved coastal protection for aquaculture	• Area of inland or coastal aquaculture protected from flooding • Area of mangrove restoration	• Satellite remote sensing	• GIS mapping of prior, existing and post-disaster land cover, land use area and infrastructure for aquaculture
Improved resilience of aquaculture sector to climate change	• Area of integrated rice–fish cultivation • Length of pond embankment protected by saplings	• Field survey	• Location-enabled mobile device survey
Improved resilience of aquaculture facilities	• Location and correct siting of aquaculture facilities	• Satellite remote sensing	• GIS mapping of aquaculture facilities prior to disaster and post-recovery location to assess if exposure is reduced

Source: Adapted from Bueno (2009).

Monitoring of climate change and other external threats

Identify how spatial technology can support monitoring of risks such as climate change

Over the past few years, many coastal and inland areas around the world have suffered severely from the impact of natural disasters, including storms, floods, droughts and salt-water intrusion. The increase in the frequency of disasters and severity of their impact is, in part, attributed to climate change (Barange *et al.,* 2018).

Livelihoods in many regions around the world are improved through aquaculture development, but this must also involve building resilience and adaptive capacity to mitigate the risks from climate change. Among the most significant impacts of climate change is the potential increase of food insecurity and malnutrition, which can be mitigated by a robust aquaculture sector.

Spatial technology can support monitoring related to climate change risks, as suggested in Table 21. Important spatial technologies include global weather satellites to monitor, *inter alia*, precipitation, paths of tropical storms, magnitude of floods, and supporting rehabilitation of natural protective barriers such as mangrove habitats. Other satellite sensors can detect and monitor ocean parameters, such as sea surface temperature, chlorophyll-*a,* salinity, currents and wave heights (see Annex 1).

If climate change is not integrated into aquaculture management systems, the impacts of these drivers of change may be profoundly negative on long-term sustainability (De Young *et al.*, 2012). Table 1 in section 2 lists and describes the potential impacts of climate change on aquaculture. Other direct and indirect impacts of climate change are:

- Temperature-related impacts specific to aquaculture, including changes to ideal temperature zones of farmed species and the increased spread of farmed fish diseases directly linked to increased temperatures.
- Greenhouse gas accumulation is also increasing the acidification of oceans, with potentially severe consequences for molluscs, crustaceans and cephalopods, mangroves, tropical coral reefs and cold-water corals.
- Rising sea levels will displace brackish and freshwaters in river deltas, prohibiting some freshwater aquaculture practices and destroying wetlands, but also creating new environments and some opportunities (e.g. for brackish water aquaculture species).
- Observation and models suggest that a warmer climate results in increased storm activity (intensity and occurrence). Frequent intense storms endanger the lives of fishers, fish farmers and coastal/riparian/lacustrine communities directly and can cause damage to fisheries and aquaculture infrastructure and housing and pose additional threats for coral reefs and mangroves.
- More subtly, storms stir waters, causing temperatures and nutrient levels to change throughout the water column, having likely consequences for species distribution. More frequent and more severe storms and floods will also increase the risks that farmed species escape, having potential impacts on farm profitability and genetic biodiversity in the natural systems.

Monitoring of climate change is challenging because, despite the unprecedented pace of global warming, the time frame means that long-term monitoring is required to precisely identify and characterize the stresses on biological and social systems that climate change may cause. Several disturbances have been observed around the world that could be related to a changing climate (e.g. negative impacts caused by ocean acidification to shellfish growth, survival rates and populations, increased occurrence of HABs, salinization of coastal areas, and saltwater intrusion upstream of rivers). Although it is often not clear that a changing ocean climate is directly responsible, the complex interactions involved are increasingly being unraveled and understood.

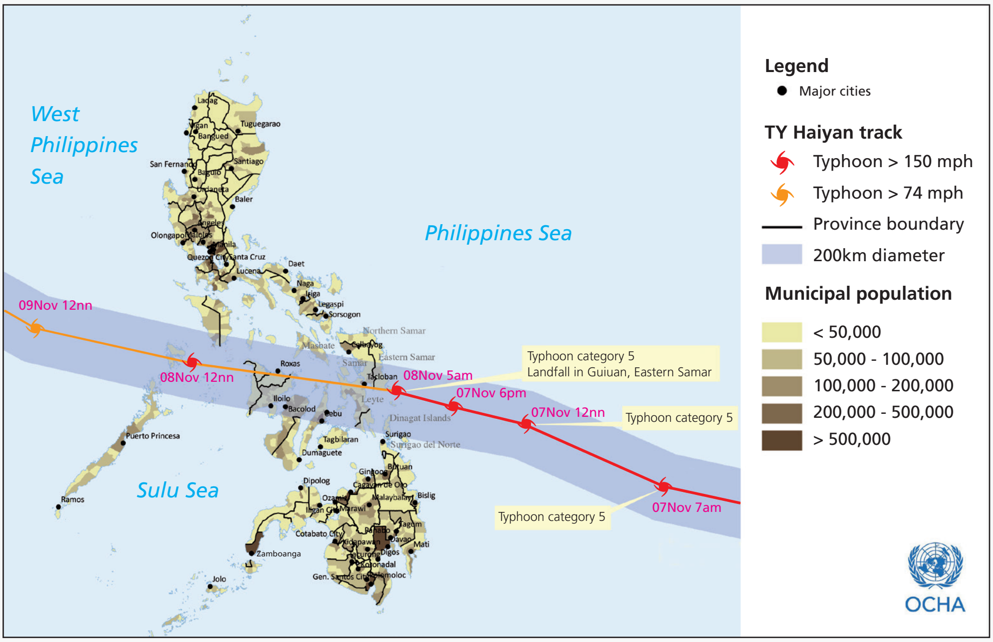
Spatial technology is an essential component of long-term monitoring of climate-related variables and provides a valuable component of climate change models used to generate impact predictions. An example of severe weather tracking is provided in Box 16.

BOX 16

Typhoon Haiyan (Yolanda) projected track, Philippines, 6 November 2013

The central Philippines suffered the impacts of Super Typhoon Haiyan, locally named Yolanda. Humanitarian Response (Philippines), provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), indicated that initial needs assessment had prioritized shelter, food, health, water, sanitation and hygiene, camp management and logistics.

The scale of likely damage and subsequent relief needed was approximately calculated using GIS to establish the populations affected along the typhoon track, plus the location, types and amounts of land vulnerable to flooding and the roads liable to be affected.



The Association of Southeast Asian Nations Coordinating Centre for Humanitarian Assistance on disaster management tracked Haiyan's development using the Disaster Monitoring and Response System. The Centre is increasing early warning activities for the region, releasing valuable "Flash Updates" on its website and via social media. Additionally, the Government of Viet Nam is utilizing a customized system, called VinAWARE, to monitor the hazards activity.

Source: Modified from UNOCHA (2013).

Notes:

- *Data source(s): GADM, PDC, NSO, NSCB, PAG-ASA.*
- *Scale: 1:10,000,000*
- *The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Creation date: 8 November 2013.*

Working with local communities in Peru to apply spatial technology

Spatial technology can make an important contribution to stakeholder communication and consultation across the DRM cycle. It is essential to be aware of the information requirements of communities involved in aquaculture disaster preparedness and response, so as to ensure the appropriate use of spatial technology and to meet their needs. This can only be achieved through close collaboration between the aquaculture community and those with expertise in the use of spatial technologies.

In disaster situations, communities can use spatial technologies to inform disaster response agencies, including those involved in aquaculture, of the needs and priorities for assistance. When visualized in maps, crowdsourcing and remote sensing data can be powerful tools to communicate the impacts of a disaster and the need for humanitarian assistance. During recovery, communities can be active participants in monitoring and evaluation of rehabilitation using spatial technology.

Coordination of emergency preparedness and response needs to be led by competent agencies that are able to coordinate partners and use aquaculture-relevant spatial technologies in a timely and efficient manner.

This photograph shows technical personnel working directly with members of a community in Peru to demonstrate the use of drones for aerial photography to assess damage, mapping for planning and response, and delivery of supplies.

Courtesy of WeRobotics.

4

Communication and coordination

Involvement of stakeholders is a key factor in successful management. Spatial technology can make an important contribution to aquaculture sector stakeholder communication and consultation across the DRM cycle. Well-designed maps, along with summary tables and charts generated from spatial analysis, are very effective for communicating complex ideas.

Resource management and planning has increasingly moved beyond traditional top-down, agency-driven decision-making towards processes that involve stakeholders in participatory mapping. This is explained in more detail in the following subsections.

4.1 CONSULTATION WITH RELEVANT STAKEHOLDERS

Participatory mapping enhances consultation with stakeholders, and those involved in mapping increasingly find themselves in a new role of engaging stakeholders – working with the public to collect, depict and interpret new information that helps when making decisions about resources. Participatory mapping is the convergence of stakeholder participation and mapping techniques and is becoming a popular tool. These maps go beyond the physical features portrayed in traditional maps; nearly everything valued by the community can be expressed in spatial terms and represented on a participatory map, including social, cultural and economic features. The process used to create the maps is as valuable as the maps themselves, since participants often find themselves more fully engaged than they would have been otherwise (NOAA, 2017).

Participatory mapping is a general term used to define a growing toolbox of techniques that can help communities make land use decisions. The spatial technologies described in sections 2.2 and 2.3 of this guide can contribute to participatory mapping, depending on the group of stakeholders involved, for example (NOAA, 2017):

- Wall maps – stakeholder consultation often includes discussions around a large printed map, which is "marked up" to reflect priorities and concerns.
- Digital maps – such as PDF files can be annotated or have digital markup, which allows a similar process to occur using a mobile tablet device or email.
- Onsite walk – in the location of interest, stakeholders collect tracks and geo-tagged photos using location-enabled devices such as smartphones or tablets, or using handheld GPS units.
- Online mapping – a web application is established to gather stakeholder inputs, e.g. using OpenStreetMap (https://www.openstreetmap.org).

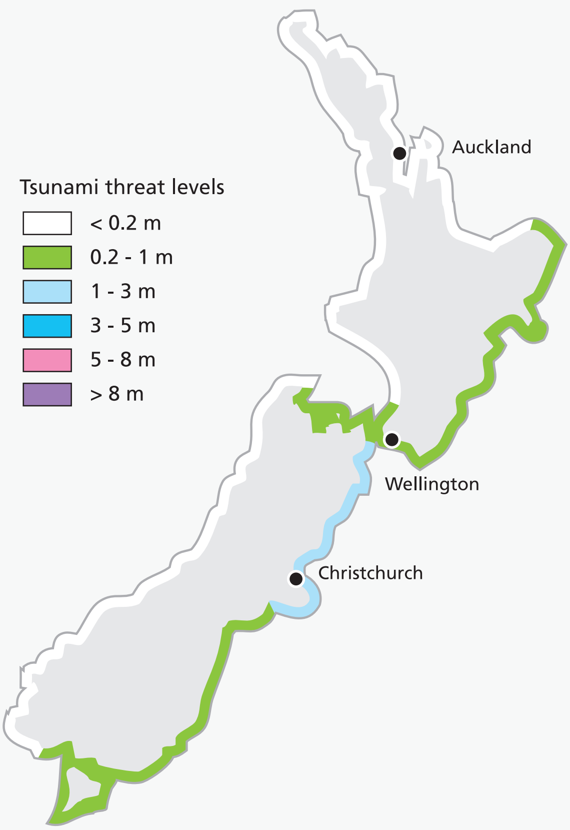
4.2 INFORMATION OUTPUT TO DECISION-MAKERS

As with stakeholder consultation, well-designed maps can facilitate decision-making. Setting priorities regarding risk reduction and disaster recovery will involve consideration of multiple complex factors, which will usually have a spatial component. Maps can visually communicate areas or facilities that are deemed most at risk or indicate where damaged facilities have the most impact on the local community.

Maps do not need to be complicated and should clearly communicate information to users regardless of the disaster management phase. Box 17 illustrates an example of an initial report regarding tsunami threat levels in New Zealand soon after the 2016 earthquake occurred.

BOX 17

New Zealand earthquake (November 2016)



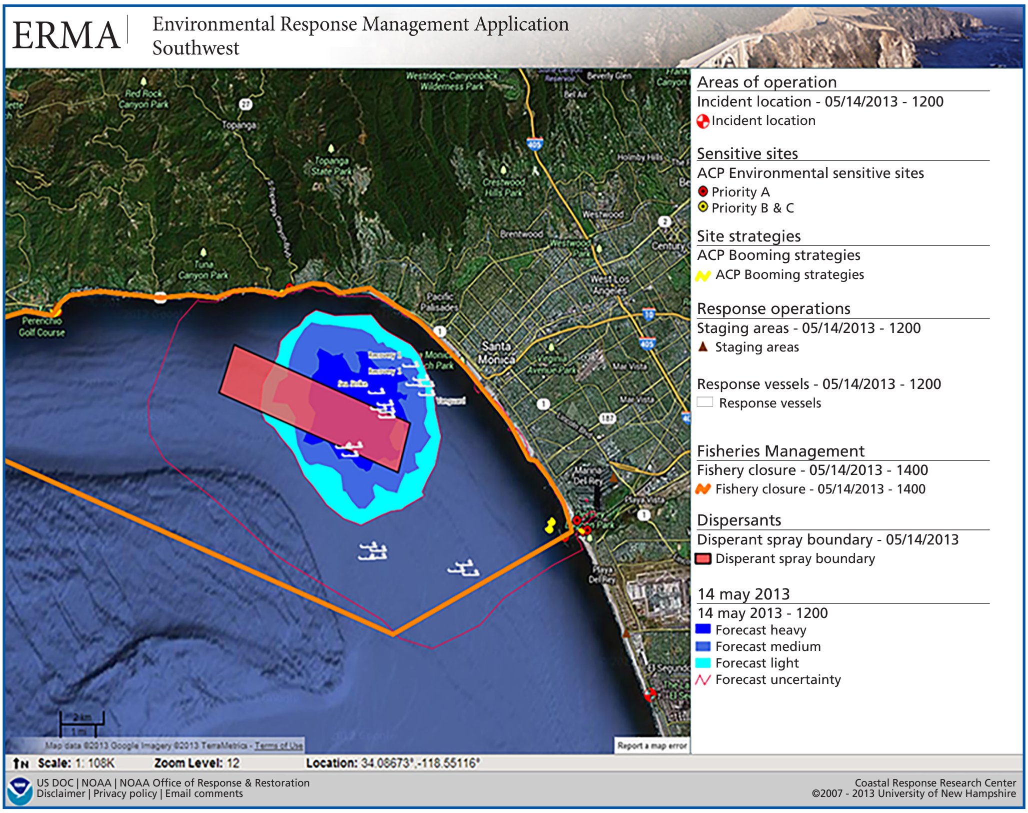
Source: Ministry of Civil Defence, New Zealand. Modified from BBC (2016).

Just after midnight on Monday, 1 November 2016, the epicentre of the earthquake occurred northeast of Christchurch, New Zealand. The earthquake was a magnitude 7.8 and was felt as far afield as Wellington, the capital city located on the North Island, 200 km (120 miles) away. As a result of the earthquake, a tsunami arrived about two hours after the initial impact. In an attempt to prevent further disaster, spatial planning was used to determine areas that would be heavily impacted by the incoming tsunami. This planning allowed officials to warn everyone along the eastern coast to head inland or for higher ground quickly. A gauge at Kaikoura, 181 km (112 miles) north of Christchurch, measured a wave 2.5 m (8 ft, 2 ins) in height in the early hours of the morning, according to Weatherwatch.co.nz.

During the disaster response stage, rapid map production will assist disaster situation managers to prioritize efforts. Internet mapping (e.g. web-based GIS) systems can enable a common operating picture of response activities. As an example, Figure 10 illustrates Environmental Response Management Application (ERMA) for the Southwest region of the United States of America, an online mapping tool for the coastal region of California. It collates a variety of data sets into a single interactive map, providing a quick visualization and improving communication and coordination for environmental response, planning and restoration. Highlighted data sets include habitats and natural resources at risk, area contingency plans, and real-time weather and operational data.

Mobile applications and community cloud-based mapping systems, such as Ushahidi, can heighten decision-makers' situational awareness early in the disaster response stage, e.g. response to earthquakes, storms and complex disasters.

FIGURE 10 **Common operating picture map for a simulated oil spill in Santa Monica Bay, United States of America**



Source: NOAA (2018).

Note: In the spring of 2013, Southwest ERMA was used in a large-scale oil spill training drill in El Segundo, California, just outside of Los Angeles, United States of America. As the common operating picture for the drill, ERMA allowed all responders to visualize simulated impacts of a potential oil spill in Santa Monica Bay.

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Annex 1 – Spatial data and data products

A large set of remote sensing data sources can help support needs across all stages of the disaster risk management cycle. A selection of the most useful satellite remote sensing data sets is listed in Table A1.1, grouped by disaster type.

Examples of satellite remote sensing platforms are listed in Table A1.2 based on the ability to measure parameters of interest, which can be reviewed in further detail using the World Meteorological Organization Observing Systems Capability Analysis and Review Tool; see www.wmo-sat.info/oscar).

Table A1.1
Examples of earth observation data supporting aquaculture disaster risk management

Natural ((hydrometeorological) disasters	Parameters	Sources	Examples
Hurricanes	Wind speed (horizontal)	Weather satellites	Meteosat
Floods	Precipitation intensity	Precipitation radar satellites	GPM
	Flood extent	Imaging radar satellites	Sentinel-1, RADARSAT-2
	Shallow water; bathymetry (to ˜ 20 m)	Optical satellites	Landsat-8, Sentinel-2, Worldview-3
Drought	Waterbody extent	Imaging radar satellites	Sentinel-1, RADARSAT-2
	Lake levels	Radar altimetry	JASON-2
Severe winter	Sea-ice cover	Imaging radar satellites	Sentinel-1, RADARSAT-2
	Snow cover	Radar satellites	Aqua/Terra, Landsat-8, Sentinel-2
Climate change	Sea surface temperature	Optical/thermal satellites	Aqua/Terra, Sentinel-3
	Dissolved organics/ocean colour (CDOM)	Optical satellites	Aqua/Terra, Sentinel-3
	Sea surface salinity	Radar satellites	SMOS, SMAP
	Vegetation type/health	Optical satellites	Landsat-8, Sentinel-2
Natural (geophysical) disasters			
Earthquake	Structural damage	Imaging radar satellites	Sentinel-1, RADARSAT-2
Volcanic eruption	Ocean suspended sediment	Optical satellites	Aqua/Terra, Sentinel-3
Tidal surge and tsunami	Wave directional energy	Radar altimetry	JASON-2
	Significant wave height	Radar altimetry	JASON-2
	Wind speed (horizontal)	Radar altimetry	JASON-2
	Ocean dynamic topography	Radar altimetry	JASON-2
	Ocean turbidity (DAC)	Optical satellites	Aqua/Terra, Sentinel-3
Natural (biological) disasters			
	Ocean chlorophyll	Optical satellites	Aqua/Terra, Sentinel-3
Technological disasters			
Oil spills	Oil spill cover	Radar satellites	Sentinel-1, RADARSAT-2

TABLE A1.2
World Meteorological Organization satellite system sensor evaluation links

Satellite platform – sensor	OSCAR evaluation link
Landsat 8 – OLI	www.wmo-sat.info/oscar/instruments/view/375
Sentinel-2 – MSI	www.wmo-sat.info/oscar/instruments/view/312
ALOS-3 – HISUI	www.wmo-sat.info/oscar/instruments/view/946
DMC/Deimos-1 – SLIM6	www.wmo-sat.info/oscar/instruments/view/513
Deimos-2 – HiRAIS	www.wmo-sat.info/oscar/instruments/view/964
WorldView-2 – WV110	www.wmo-sat.info/oscar/instruments/view/696
Aqua/Terra – MODIS	www.wmo-sat.info/oscar/instruments/view/296
Sentinel-3 – OLCI	www.wmo-sat.info/oscar/instruments/view/374
Metop – IASI	www.wmo-sat.info/oscar/instruments/view/207
GCOM-C1 – SGLI	www.wmo-sat.info/oscar/instruments/view/505
RADARSAT-1 – SAR-C	www.wmo-sat.info/oscar/instruments/view/445
Sentinel-1 – SAR-C	www.wmo-sat.info/oscar/instruments/view/450
Kompsat-5 – COSI	www.wmo-sat.info/oscar/instruments/view/89
SMOS – MIRAS	www.wmo-sat.info/oscar/instruments/view/287
SAC-D (CONAE) – Aquarius	www.wmo-sat.info/oscar/instruments/view/41
JASON-2 – Poseidon-3	www.wmo-sat.info/oscar/instruments/view/407
GPM – DPR	www.wmo-sat.info/oscar/instruments/view/125
Metop – ASCAT	www.wmo-sat.info/oscar/instruments/view/47

Annex 2 – Data portals

TABLE A2.1
Remote sensing image catalogues

Name	URL
Airbus DMC Constellation (SPOT, DMC, Pleiades)	http://www.intelligence-airbusds.com/satellite-data/
United States Geological Survey – EarthExplorer (especially Landsat-8)	http://earthexplorer.usgs.gov http://landsat.usgs.gov/landsat8.php
United States National Aeronautics and Space Administration – Earth Observing System Data and Information System (EOSDIS – multiple sensors)	http://reverb.echo.nasa.gov
European Space Agency (ESA) data products catalogue (multiple sensors)	https://earth.esa.int/web/guest/data-access/browse-data-products
DigitalGlobe Image Finder (WorldView, GeoEye, QuickBird)	https://browse.digitalglobe.com/imagefinder
NOAA Emergency Response Imagery NOAA Environmental Visualization Library	https://storms.ngs.noaa.gov https://www.nnvl.noaa.gov/Default.php

TABLE A2.2
Environmental data sources

Name	URL
Global Observing Systems Information Center – Global Ocean Observing System (GOOS)	www.ioc-goos.org
FAO GeoNetwork	www.fao.org/geonetwork
United Nations Environment Programme – Environmental Data Explorer	http://geodata.grid.unep.ch
USGS Earth Observing System Data and Information System	https://search.earthdata.nasa.gov
NOAA Comprehensive Large Array – Data Stewardship System	www.class.ngdc.noaa.gov
World Meteorological Organization – Severe Weather Information Centre	http://severe.worldweather.wmo.int
United States – NOAA National Weather Service	www.weather.gov
NOAA National Centers for Environmental Information	https://www.ncdc.noaa.gov/data-access
Meteoalarm Europe	www.meteoalarm.eu

TABLE A2.3
Disaster response information portals

Name	URL
Food and Agriculture Organization of the United Nations – Global Information and Early Warning System (GIEWS)	www.fao.org/giews/english/index.htm
United Nations Office for the Coordination of Humanitarian Affairs	www.unocha.org
Global Disaster Information Network	www.gdin.org
Humanitarian Response	https://www.humanitarianresponse.info
United States Geological Survey (USGS) Emergency Response	https://hdds.usgs.gov

TABLE A2.4
Hazard and risk models and statistics

Name	URL
International Charter "Space and Major Disasters" map of past activations (major disaster events)	https://www.disasterscharter.org/web/guest/activations
Columbia University Center for Hazards and Risk Research – disaster hotspots	www.ldeo.columbia.edu/chrr/research/hotspots
Mariculture AquaModel – numerical modelling of marine fish farms	www.aquamodel.org
NOAA National Centers for Environmental Information map of past major tectonic events	http://maps.ngdc.noaa.gov/viewers/hazards
Dartmouth Flood Observatory – Global Active Archive of Large Flood Events	http://floodobservatory.colorado.edu/Archives/index.html

Annex 3 – Technical support and training

TABLE A3.1
Online technology tutorials

Source	URL
Karen E. Joyce, Kim C. Wright, Sergey V. Samsonov and Vincent G. Ambrosia. 2009. *Remote sensing and the disaster management cycle. Advances in geoscience and remote sensing.* Gary Jedlovec, ed. InTech, DOI: 10.5772/8341.	https://www.intechopen.com/books/advances-in-geoscience-and-remote-sensing/remote-sensing-and-the-disaster-management-cycle
CEOS ESA – *Satellite earth observations in support of disaster risk reduction* (remote sensing for disaster risk reduction)	www.eohandbook.com/eohb2015/files/CEOS_EOHB_2015_WCDRR.pdf
Natural Resources Canada – remote sensing tutorial	www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309
Federation of American Scientists – remote sensing tutorial	http://fas.org/irp/imint/docs/rst/Front/tofc.htmlhttp://fas.org/irp/imint/docs/rst/Front/tofc.html
SEOS (remote sensing)	www.seos-project.eu/modules/remotesensing/remotesensing-c00-p02.html
University of Las Palmas of Gran Canaria (remote sensing tutorial)	www.grss-ieee.org/wp-content/uploads/2014/07/EN_TUTORIAL_COMPLETO.pdf

TABLE A3.2
Conferences, workshops and webinars on remote sensing and disaster risk management

Name	URL
United Nations/India Workshop on the Use of Earth Observation Data in Disaster Management and Risk Reduction	www.unoosa.org/oosa/en/ourwork/psa/schedule/2016/workshop_india.html
Gi4DM annual conference (DRM geo-information) 2015	www.gi4dm.net
Global Ocean Observing System webinars (ocean science)	www.ioc-goos.org
UN World Conference on Disaster Risk Reduction 2015	www.wcdrr.org
International Disaster and Risk Conference – IDRC Davos 2016	http://idrc.info
Annual Conference of the International Society for Integrated Disaster Risk Management (IDRiM 2015)	www.tifac.org.in/index.php?view=article&id=963
International Geoscience and Remote Sensing Symposium	Future conferences: www.grss-ieee.org/conferences/future-igarss Past conferences: www.grss-ieee.org/past-igarss
International Society for Photogrammetry and Remote Sensing (XXIII ISPRS Congress) 2016 (remote sensing)	www.isprs2016-prague.com
Canadian Symposium on Remote Sensing	https://crss-sct.ca/events/events-archive/

TABLE A3.3
Commercial GIS and remote sensing software support and training

Software	Type	URL
ArcGIS	GIS	www.esri.com/training/main/training-catalog
QGIS	GIS	https://www.qgis.org/en/site/forusers/commercial_support.html
Manifold (third party)	GIS	www.gisadvisor.com
GRASS	GIS	grass.osgeo.org/support/commercial-support
GeoServer	GIS	http://geoserver.org/support
PostGIS	GIS	http://postgis.net/support
SQL Server	GIS	www.microsoftvirtualacademy.com/product-training/sql-server
Oracle	GIS	http://education.oracle.com/pls/web_prod-plq-dad/ou_product_ca-tegory.getFamilyPage?p_family_id=32&p_mode=Training
ERDAS Producer Suite	RS	www.hexagongeospatial.com/support/training
PCI Geomatica	RS	www.pcigeomatics.com/resources-support/geomatica/training
ENVI	RS	www.exelisvis.com/Learn/Training.aspx
eCognition	RS	www.ecognition.com/support/training
Socet GXP	RS	https://mygxp.socetgxp.com/SelfService/faces/ss/base/ev/Trainin-gHome.jspx
IDRISI	RS / GIS	www.clarklabs.org/services/training.cfm

TABLE A3.4
Users' discussion groups on GIS and remote sensing

Software	URL
ArcGIS	http://forums.esri.com
QGIS	https://www.qgis.org/en/site/forusers/support.html
Manifold	www.georeference.org/forum
GRASS	http://grass.osgeo.org/support/community
SAGA	www.saga-gis.org/en/about/usergroup.html
GeoServer	http://osgeo-org.1560.x6.nabble.com/GeoServer-f3786387.html
MapServer	https://trac.osgeo.org/mapserver/wiki/MUGs
Spatialite	https://groups.google.com/forum/#!forum/spatialite-users
PostGIS	http://lists.osgeo.org/mailman/listinfo/postgis-users, https://groups.google.com/forum/#!forum/postgis-users
SQL Server	www.sqlpass.org/passchapters/localchapters.aspx
Oracle	www.oracle.com/us/corporate/customers/user-groups/index.html, www.ioug.org/
ERDAS	https://support.hexagonsafetyinfrastructure.com/infocenter/index?page=forums&forum=507301383c17ef4e013d8dfa30c2007e9e
ENVI	www.exelisvis.com/Support/Forums/tabid/184/GroupID/9/ForumID/13/Default.aspx
eCognition	www.ecognition.com/community
IDRISI	https://forums.clarklabs.org
ILWIS	http://ilwis.forum.52north.org
Orfeo Toolbox	https://groups.google.com/forum/#!forum/otb-users
ESA BEAM	www.brockmann-consult.de/cms/web/beam/forum
ESA NEST	https://earth.esa.int/web/nest/user-community/forum
Opticks	http://sourceforge.net/p/opticks/mailman/opticks-users

TABLE A3.5
Professional remote sensing and GIS organizations

Name	Focus	Region
Canadian Institute of Geomatics	GIS	Canada
Canadian Remote Sensing Society (CRSS)	Remote sensing	Canada
Geospatial Information and Technology Association (GITA)	AM/FM GIS	United States of America
Association of American Geographers (AAG)	Geography	United States of America
Management Association for Private Photogrammetric Surveyors (MAPPS)	Photogrammetric remote sensing	United States of America
IEEE Geoscience and Remote Sensing Society	Remote sensing	United States of America
American Society for Photogrammetry and Remote Sensing (ASPRS)	Remote sensing and photogrammetry	United States of America
International Society for P hotogrammetry and Remote Sensing (ISPRS)	Remote sensing and photogrammetry	United States of America
Urban and Regional Information Systems Association (URISA)	Urban and regional GIS	United States of America
Grupo SIG-FAM – Sistemas de Información Geográf-ica	Urban GIS	Chile
Organización de los Proyectos de Sistemas de Información Geográfica Territoriales	Geography	Cuba
Conseil National de l'Information Geographique	Geography	France
Asociación Española de Sistemas de Información Geográfica	Geography	Spain
Association for Geographic Information	Geographic data	United Kingdom
Remote Sensing and Photogrammetry Society (RSPSoc)	Remote sensing and photogrammetry	United Kingdom
European Umbrella Organization for Geographic Information	Geography	European Union
Society of South African Geographers	Geography	South Africa
International Association of Chinese Professionals in Geographic Information Sciences	Geography	China
Tokyo Geographical Society	Geography	Japan
Open Source Geospatial Foundation	GIS software develop-ment	International
Open Geospatial Consortium (OGC)	Spatial standards	International

Source: Meaden and Aguilar-Manjarrez (2013).

This new Guide describes the application of spatial technology to improve disaster risk management (DRM) within the aquaculture sector. DRM requires interrelated activities to ensure prevention, preparedness (including early warning), response and recovery for a wide range of natural, technological and complex disasters that can impact aquaculture operations and livelihoods.

Spatial technology refers to systems and tools that acquire, manage and analyse data that have geographic context. Some of the technologies include satellite remote sensing, aerial surveys, global positioning systems, geographic information systems, information and communication technology and other data gathering sensors used, for instance, in meteorology. Spatial technology supports activities across all phases of the DRM cycle and its rapid development provides enhanced opportunities to support DRM within the aquaculture sector.

This Guide is organized in two parts. Part one is the "guidance"; it is the main body of the document and describes the processes and steps for the use of spatial technology within DRM for aquaculture. Part two includes selected country case studies from Bangladesh, the Gulf of Mexico and the Caribbean, and Indonesia to illustrate the application of spatial technology in DRM for aquaculture at the national level within local contexts.

Best practices at the farm and area management levels, supported by spatial technology, reduce volatility and risks and thus facilitate investment. Countries that would like aquaculture to grow sustainably and reliably are encouraged to use this Guide in order to support spatial planning approaches and protect responsible investors.

A separate summary version accompanies this publication.

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