Food and Agriculture Organization of the United Nations

Guidance on spatial technologies for disaster risk management in aquaculture

Summary version

Cover image:

Copernicus Programme satellite constellation

The European Copernicus Programme is an EU-wide programme that uses satellite and *in situ* observations to deliver high resolution data to promote a better understanding of the planet and manage the environment.

Copernicus' services support a wide range of applications, including environmental protection, management of urban areas, regional and local planning, agriculture, forestry, fisheries, health, transport, climate change, sustainable development, civil protection and tourism.

The Copernicus Sentinel satellites combine a range of technologies, including multi-spectral sensors for land, ocean and atmospheric monitoring, and radar sensors that provide unique ocean and land monitoring capabilities. 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.

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Summary version

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1. Introduction

The FAO *Guidance on spatial technologies for disaster risk management in aquaculture* (Aguilar-Manjarrez, Wickliffe and Dean, 2018) provides concepts and technical information to raise awareness and improve knowledge of the spatial technologies available to decision-makers, managers and technical personnel involved in disaster risk management (DRM) for aquaculture. This is a summary of the Guide. It highlights key concepts, case studies and policy recommendations for using these technologies in the aquaculture sector.

The Guide addresses the use of spatial technologies that support those working to reduce disaster risks and respond to emergencies. It lays down the principles for using spatial technologies in DRM and will therefore remain relevant even in the context of rapid technological innovation and the advancement of these technologies.

The processes and steps for using spatial technology within DRM for aquaculture are described and explained, taking into account factors such as accessibility, limitations, complementary data and tools, human resources and financial resources.

Case studies in Bangladesh, the Gulf of Mexico and the Caribbean, and Indonesia illustrate the local, national, and regional application of spatial technologies in DRM for aquaculture. Each case study recommends steps for using spatial technologies to support the DRM process.

2. Who should use this Guide?

This Guide provides support to:

Planners – it offers a framework for government, aquaculture producers and insurers to plan and use spatial technologies and data for DRM.

Implementers – for 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 – it improves understanding of how spatial technology can contribute to monitoring and evaluation of response and recovery efforts in aquaculture.

3. Disaster risk management and aquaculture

All segments of the aquaculture production and supply chain are vulnerable to disaster events, which makes the tasks of emergency preparedness, response, and recovery and rehabilitation particularly demanding.

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.

4. Why do we need spatial technologies for disaster risk management?

Aquaculture activities occur inland, along coasts and in marine environments, leaving the associated gear and cultured organisms exposed to a wide range of hazards.

More than 80 percent of global aquaculture production is produced by small- to medium-scale enterprises (FAO, 2018a). This underscores the importance of DRM to global food and nutrition security.

Spatial technologies support better aquaculture management practices from farm to regional scales.

Reducing the exposure and vulnerability of communities and aquaculture operations in areas where hazards occur requires geographic information on populations, the environment and hazards.

Spatial technologies support the capture, management, analysis and distribution of this information across all phases of DRM in the aquaculture sector.

These technologies include: satellite remote sensing, global positioning systems (GPS), aerial surveys, drones, remotely operated vehicles (ROVs), autonomous underwater vehicles and underwater sensors, geographic information systems (GIS) and information and communication technologies (ICTs) that integrate or support spatial technologies.

Over the past 50 years, there has been unremitting growth in computing power in terms of processing speed, data storage capacity, analytical and computer graphics capability. Likewise, the application and use of information technologies, especially spatial technology, has grown steadily. The revolution in ICTs, including computers, location-enabled and Internet-connected mobile devices and the numerous services associated with them, has transformed many of the processes that can be used in DRM for aquaculture.

Continuing advances in remote sensing, GIS and ICTs provide opportunities for new, more effective DRM for aquaculture.

5. Types of disasters and their impacts on aquaculture

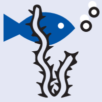
A disaster that may disrupt aquaculture operations and jeopardize livelihoods can be one of three general types: (i) natural (e.g. hydrometeorological, geophysical or biological); (ii) technological; or (iii) complex.

In addition, it is expected that climate change will result in increased frequency, severity and/or complexity of extreme events (e.g. hurricanes, winter storms, high current speeds) and will impact the natural resources required for aquaculture, such as water, feed and space (FAO, 2018b).

The impacts of disasters on aquaculture operations and livelihoods vary according to the type of disaster, as shown in **Table 1**.

TABLE 1. Disaster impacts on aquaculture operations and livelihoods[1]

Disaster category	Disaster type	Impacts on aquaculture operations	Impacts on livelihoods
Natural (hydrometeo-rological)	Hurricanes or cyclones	• Disruption of operations • Damage to infrastructure and equipment • Disruption of marketing timetable and transport to market • Loss of farmed plants and aquatic animals	• Destruction or loss of physical assets, and loss of or damage to stock • Reduced value of operations • Deaths and/or health problems of farmers and farm workers degrade human capital
	Floods	• Disruption of operations • Damage to infrastructure and equipment • Disruption of marketing timetable and transport to market • A large influx of freshwater can cause massive mortalities of cultured marine species • Escape of cultured species • Increased eutrophication and algal blooms	• Loss of physical assets • Damage to productive capacity of land • Reduced value of land • Deaths 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	• Freshwater supply severely restricted, leading to reduced production • Cultured species not tolerant to heat may die • Freshwater culture systems cannot operate	• Prolonged drought may preclude freshwater aquaculture • Restricted freshwater supply may lead to water use conflicts
	Severe winter	• Cultured species not tolerant to cold may die • Damage to infrastructure and energy supply	• Damage to stock • Reduced value of operations • Low productivity • Cost of rebuilding for resilience
Natural (geophysical)	Earthquake	• Disruption of operations • Damage to infrastructure and equipment • Disruption of marketing timetable and transport to market	• Destruction or loss of physical assets • Damage to productive capacity of land • Reduced value of operations • Cost of rebuilding for resilience • Deaths 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 • Deaths and/or health problems of farmers and farm workers degrade human capital
	Tidal surge and tsunami	• Severe disruption of operations • Destruction or severe damage to infrastructure • Probable death of farmers and farm workers • 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 • Deaths and/or health problems of farmers and farm workers degrade human capital • Cost of rebuilding for resilience

Disaster category	Disaster type	Impacts on aquaculture operations	Impacts on livelihoods
Natural (biological) 	Disease outbreaks	• Destruction of stocks to prevent spread of disease • Limited operations • Impacts on brood fishes • Quarantine periods	• Loss of income, markets • Costly health management measures • Temporary loss of production
	Harmful algal blooms and hypoxia	• Closure of farming areas • Early harvests • Fish kills or contamination of stocks	• Loss of income, markets • Costly health management measures • Lengthy break in production
Technological 	Oil spills, chemical spills and chemical runoff	• Fish kills or contamination of stocks • Closure of operations until clean-up is complete	• Loss of income, markets • Costly health management measures
	Nuclear leak	• Long-term disruption of operations • Contamination of water and soils	• Loss of income, markets • Health problems of farmers and farm workers degrade human capital
Complex 	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; markets • Evacuation and relocation

[1] See also Table 12, p.111 in Cattermoul, B., Brown, D. & Poulain, F. (eds). 2014. *Fisheries and aquaculture emergency response guidance.* Rome, FAO. 167 pp. (also available at www.fao.org/3/a-i3432e.pdf)

6. Types of spatial technologies for disaster risk management

Spatial technologies are increasingly prevalent in society, with location-enabled devices and the use of Internet-enabled services being key features of the digital revolution.

Spatial technologies are systems and tools that acquire, manage and/or analyse geographic or locational data. They include remote sensing technologies, such as satellite images, drones, underwater sensors, aerial surveys, GPS, GIS and a multitude of other data gathering sensors used in meteorology and oceanography.

Remote Sensing

Satellite remote sensing

Images derived from remote sensing provide vital inputs for disaster preparedness and often provide the first view of the extent and impacts of a disaster. Satellite images provide consistent data over large areas with impressive detail. They are suitable for meeting many of the information requirements of aquaculture operations (e.g. technical requirements for culture installations such as optimal depths and ocean/water current speeds;

and environmental requirements for the growth and well-being of cultured species such as sea surface temperature, primary productivity and turbidity).

Global positioning systems

GPS are positioning and navigation systems for determining locations using signals from a network of satellites orbiting earth. 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. GPS are globally commonplace because they are integrated within smartphones.

Aerial survey

During an emergency response, aerial surveys provide critical and immediate reconnaissance information. Digital photographs with geographic coordinates can be plotted on maps and used together with satellite images to provide a complete picture of the DRM process.

Drones

Drones, also known as unmanned aerial vehicles (UAVs), promise new capabilities for humanitarian action following disasters.

Drones are an area of rapid innovation in remote sensing. The companies, platforms and capabilities of systems, as well as the rules around their use, are evolving rapidly.

Their rapid and easy deployment make drones most appropriate for short-notice acquisition of very high-resolution images (e.g. 5–20 cm) over small areas (a few square kilometres) in support of an emergency response.

Remotely operated vehicles, autonomous underwater vehicles and underwater sensors

Sensors and communication systems can mitigate risks that become more serious as marine aquaculture operations increase in size, capacity and complexity, and as farming moves into dynamic offshore environments.

Sensors can provide real-time data to land-based receivers, including mobile devices. At the regional level, sensor systems can collect vast amounts of data that can help to predict natural disaster events (e.g. severe storms) and hazards occurring over large areas.

At the farm level, underwater sensor systems provide operational information. ROVs can assist with a range of operational and disaster response actions, including cage inspection and repair, removal of dead stocks, sea lice inspection, damage inspection and net pen cleaning.

Geographic information systems

GIS are digital systems for the capture, storage, management, analysis, and visualization of geospatial data (Meaden and Aguilar-Manjarrez, 2013). GIS can integrate GPS data with many other data to better visualize and understand where things are, how they relate, and what actions to take. Using GIS allows insight into questions, such as:

- Which facilities may be compromised by a tsunami?
- Where are the aquaculture cages exposed to historical storm events?
- Where is damaged aquaculture infrastructure located post-disaster?
- Which aquaculture facilities are within 10 miles of the earthquake epicenter?

Emerging information and communication technologies

Over the past two decades, ICTs have dramatically transformed society and economic development.

Several tools have been developed for DRM that can be applied in the aquaculture sector. One of these is GNOME – General NOAA Operational Modelling Environment (NOAA, 2018).

Addressing tools

In many countries, the accuracy of addresses and their geographic location is poor and this can create challenges for DRM. To tackle this issue, "what3words" provides a unique three-word combination for every 3 m × 3 m square across the entire planet (http://what3words.com). Using words means non-technical people can communicate any location quickly and accurately.

Mobile devices and cloud-based data systems

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.

Weather forecasts and location-enabled severe weather warnings contribute to disaster preparedness. Field data collection during an emergency response is greatly facilitated by agile, portable digital devices.

Crowdsourcing

Crowdsourcing uses the knowledge and observations of the public and is an important source of data and information. Crowdsourcing can include contributions from anywhere in the world through online applications and from those directly affected by a disaster. For instance, using platforms like OpenStreetMap allows people to freely map the extent of damage, or where they are located, after a disaster event.

Sensor web and the Internet of Things

A network of sensors linked by software and the Internet is referred to as a sensor web or the Internet of Things.

Underwater sensors within a buoy or sonde can provide data on the location and condition of aquaculture assets, water quality parameters such as temperature and dissolved oxygen, current speed and wave height.

These technologies improve the reliability of DRM information for the aquaculture sector, including early warning, emergency response, and recovery and rehabilitation.

Models and simulations

Modelling is a fundamental component of many activities designed to improve knowledge and support decision-making throughout the DRM cycle. In general, modelling is a process to integrate and analyse observed data to generate outputs and visualizations that help our understanding of the real world.

Some examples of models relevant to aquaculture and DRM are:

- weather forecasts, e.g. tropical storm strength and path prediction;
- water quality forecasts, e.g. harmful algal blooms;
- 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. Simulation of weather events and weather forecasting is a mature discipline that continues to improve as models improve and computational power increases.

Virtual reality is a complex form of simulation and an area of active development that is crossing over from academic disciplines to real world applications. In a virtual reality computer-driven simulation, the operator is immersed in a realistic multimedia presentation. Virtual reality systems are being used to test public perceptions of aquaculture by developing scenarios for coastal water uses and, more recently, to simulate DRM. For example, virtual reality has been used to create visualizations of the height of storm surge that could potentially occur as a result of hurricanes Florence and Michael (BBC, 2018a; 2018b).

International satellite remote sensing disaster risk management initiatives

The United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), administered by the United Nations Office for Outer Space Affairs, provides satellite-derived remote sensing products designed to assist with emergency management and disaster response (UN-SPIDER, 2017).

The International Charter Space and Major Disasters involves international organizations and private sector satellite remote sensing system operators (International Charter Space and Major Disasters, 2018; see also **Annex 1**).

Spatial technologies can be applied across the DRM cycle and for different types of disaster, as seen in **Table 2**.

TABLE 2 **Example of spatial technologies for disaster risk management**

Type of technology	Disaster risk reduction	Response	Recovery
Remote sensing			
Satellite sensors	Baseline data for detailed mapping over large areas: • land cover and coastal habitat • infrastructure and land use • water quality Early warning data: • weather • algal blooms	Rapid data for: • damage assessment • disaster relief planning	Input data for: • spatial planning of rehabilitation • monitoring of rehabilitation
Aerial survey (e.g. airplane, helicopter)	• Baseline data for detailed mapping over small areas – e.g. topographic maps and infrastructure	• Rapid data for reconnaissance and immediate damage assessment	• Input data for monitoring of reconstruction and rehabilitation
Drones	• Baseline data for detailed mapping over very small areas – e.g. land cover, land use and infrastructure	• Rapid data for damage assessment for small areas	• Input data for monitoring of reconstruction and rehabilitation

Type of technology	Disaster risk reduction	Response	Recovery
Remote sensing			
Underwater vehicles and sensors	• Operational monitoring of production systems • Data capture for early warning of deteriorating environmental conditions	• Rapid underwater assessment of damage to production systems	• Inspection of reconstruction • Data capture to confirm return to normal production conditions
Geographic information systems			
GIS	• Data capture, management and visualization for preparedness • Spatial analysis for zoning, site selection and area management.	• Maps for disaster relief planning • Maps of evolution of disaster	• Data capture, management and visualization of recovery plans • Spatial analysis for recovery planning
Emerging technologies			
Addressing tools	• Geoaddressing infrastructure for preparedness	• Communication of location, e.g. what3words	• Geo-addressing new infrastructure
Mobile devices and cloud-based data systems	• Data capture for preparedness, e.g. OpenStreetMap	• Damage data capture using mobile apps (including crowdsourcing) • Communication of impacts and response to decision-makers and public	• Data capture for inspection of reconstruction • Community reporting of reconstruction quality • Communication of rehabilitation and reconstruction plans and results to decision-makers and the public
Crowdsourcing	• Baseline data and mapping, e.g. OpenStreetMap	• Rapid damage assessment using mobile phone apps or image interpretation, e.g. Ushahidi	• Community-based monitoring of recovery
Sensor web	• Location and condition of aquaculture assets • Water quality parameters • Current speed and wave height	• Real-time tracking of water quality, current speed and wave height	• Monitoring recovery of ecosystem function • Monitoring restoration of production systems
Models and simulations	• Ecological carrying capacity • Flood and drought risk • Augmented and virtual reality for preparedness	• Tropical storm tracking • Oil spill tracking and models	• Modelling exposure of restored infrastructure

The *FAO Guidance on spatial technologies for disaster risk management in aquaculture* includes information on remote sensing and GIS software tools that are applicable to or specifically designed to support DRM.

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.

7. Spatial technology in disaster risk management

Knowing how to apply spatial technology and determining which spatial technologies are most relevant for DRM are key issues for aquaculture managers and planners. There are five applications:

A. Disaster risk reduction, prevention, impact mitigation and preparedness

Disaster risk reduction (DRR) – e.g. prevention, impact mitigation and preparedness – aims at preventing new and reducing existing disaster risk and managing residual risk (UNISDR, 2017).

DRR policies, strategies and activities contribute to strengthening livelihoods resilience and reducing damages and losses from disasters.

The contribution of spatial technologies to DRR includes providing the data, tools and visualization for:

- Defining ecosystem and political boundaries and developing a baseline.
- Conducting an aquaculture disaster risk assessment.
- Developing and testing a preparedness plan and early warning systems.
- Reviewing policy considerations for DRR.
- Reviewing aquaculture insurance requirements.

B. Emergency response: damage and needs assessment

Following a disaster event, a damage and needs assessment is carried out to inform the emergency response. If disaster preparedness is effective, good baseline information will be available, as well as emergency response plans, contingency plans and preparedness measures. However, even without this information, spatial technologies can support timely emergency response.

Carrying out in-depth and technically sound damage and needs assessments right after a disaster is challenging. The inaccessibility of certain areas, because of difficult conditions or a lack of transport, increase these challenges (Cattermoul, Brown and Poulain, 2014).

The contribution of spatial technologies to damage and needs assessment includes:

- Planning damage and humanitarian needs assessment.
- Initial impact and needs assessment to inform the response.
- Data analysis and summary to assess damage.
- Damage evaluation and calculation to estimate losses along the aquaculture value chain.

C. Recovery, rehabilitation and building back better

Recovery and rehabilitation interventions should focus on the principles of "building back better" and on protecting and strengthening livelihoods to ensure that people, communities and nations become more resilient to future shocks and longer-term processes of change.

The recovery and rehabilitation phases follow the emergency response. They are also supported by effective use of spatial technologies, providing data and tools for post-disaster planning and building back better, including:

- Identifying the main issues and factors that may facilitate or obstruct recovery and rehabilitation, or make people vulnerable to shocks.
- Reviewing current best practices and legislation regarding data sharing and access to spatial data.
- Facilitating post-disaster damage and loss data collection, analysis and field verification.
- Building upon baseline and emergency response data to support the restoration of production capacity.

D. Monitoring and assessment

Monitoring and assessment is a routine component of DRM and essential for reviewing the effectiveness of DRR efforts, response and recovery.

For DRR, this implies baseline data collection and analysis over a suitable time period of culture facility locations, supporting infrastructure, environmental parameters and critical aquaculture inputs. The ultimate goal is to determine progress in reducing the vulnerability of aquaculture to disasters.

Emergency response requires the production of situation maps with regular updates to monitor and assess changes in conditions (e.g. infrastructure, environment and people).

As soon as recovery and rehabilitation begin, the effectiveness of actions to restore ecosystem functions and improve resilience should be monitored and assessed. Eventually, the recovery efforts and post-disaster conditions will require the establishment of new baselines.

E. Communication and coordination

Involvement of stakeholders is key to the success of DRM.

Spatial technologies allow timely and meaningful communication and consultation with stakeholders during the entire DRM cycle. Well-designed maps, summary tables and charts generated using spatial analysis of high-quality data are very effective for communicating complex ideas.

Resource management and planning have increasingly moved from traditional top-down, agency-driven decision-making towards participatory processes that involve stakeholders. Maps and remote sensing images from satellites or drones are incredibly powerful tools to support participatory planning.

8. Case studies

Bangladesh

A low-lying, deltaic country, Bangladesh mostly consists of the floodplains of three large and converging river systems – the Ganges, Brahmaputra and Meghna.

Types of disasters and the role of spatial technology

Bangladesh is exposed to several risks from climate change. Its low-lying coastal terrain, dense human population and high levels of poverty render the human population and aquaculture sector particularly vulnerable to hazards and stressors:

- **Storms and floods** will increase in frequency and/or intensity and cause structural damage and salinity changes.
- **Sea level rise** will result in loss of areas available for inland pond aquaculture and loss of mangroves that shield coastal areas.
- **Inland water temperature** will increase and affect water quality and productivity.
- **Drought** will reduce water quality, leading to reduced growth rates and/or an increased incidence of diseases in cultivated species. Reduced pond levels lead to a greater risk of temperature extremes, which would affect cultured species.

Considerable scope exists for Bangladesh to apply spatial technologies to mitigate the impacts of risks caused by climate change and to develop adaptation strategies for aquaculture:

- **Hydrodynamic modelling** can assess potential flood impacts from inland sources and storm surge events.
- **Surface water extent** mapping using satellite image time series can improve understanding of flood frequency and inform disaster response and recovery plans.
- **Water temperature and salinity** monitoring can help to assess negative impacts and guide adaptive management strategies.
- **Site suitability** for aquaculture production can be modelled using geospatial climate indicators of extreme temperature and drought risk.

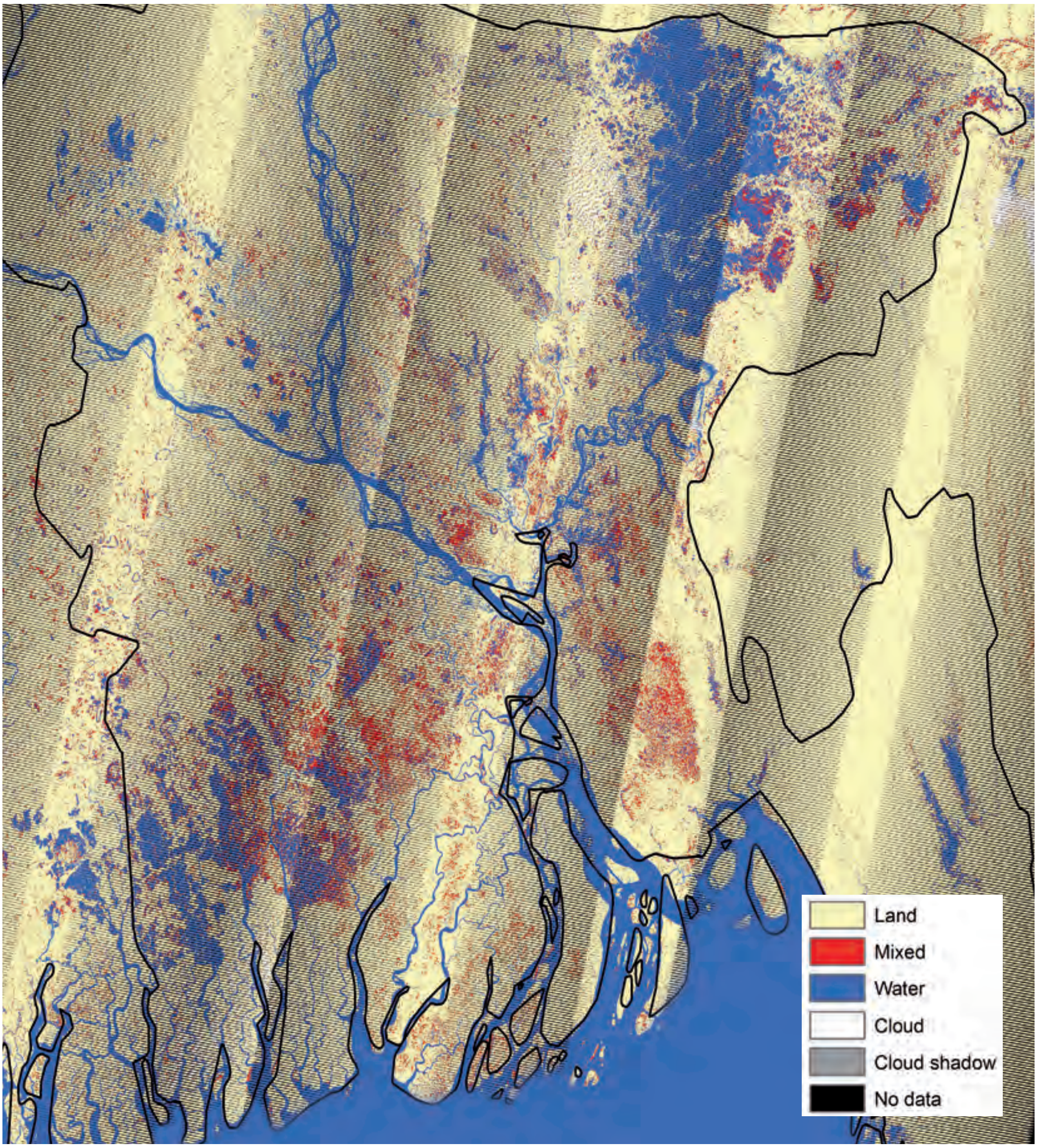
When combined with spatial modelling approaches, spatial data – including data obtained via remote sensing – can play a valuable role in highlighting areas of high and low risk, as well as potentially monitoring impacts after a disaster (**Figure 1**).

Recommended steps for using spatial technology

DRR:

- Develop aquaculture site suitability models using GIS to guide adaptive management strategies for relocating inland aquaculture facilities and for new brackish-water aquaculture operations.
- Assess changes in site suitability for pond-based aquaculture in response to climate change scenarios, and determine species appropriate for the changes in conditions.
- Assess the trade-offs in using land for new aquaculture farms or establishing new facilities.

FIGURE 1 Monitoring surface water distribution and flooding in the southern districts of Bangladesh



Courtesy of the Institute of Aquaculture, University of Stirling.

Notes:

- Remotely sensed data can be extremely useful as a means of indicating the distribution of surface water over large areas. Here, nine Landsat images recorded between 10 and 31 October 2007 have been combined to indicate areas (or pixels) containing land, water, or both land and water, over most of Bangladesh.
- The grey diagonal lines are caused by a failure of the scan line corrector on Landsat 7 in May 2003. This results in a relatively complete image in the centre of the track but a gradual loss of data towards the edges. The data loss in this instance does not detract from the overall outcome.

Response:
- Use remote sensing to assess the extent of flooding during storm surges or inland flooding.

Recovery and rehabilitation:
- Use remote sensing techniques to support planning for recovery and rehabilitation of aquaculture.

Conclusions/lessons learned

Spatial technologies have a clear role to play in DRM in Bangladesh and the appropriate capacity exists in universities and some government agencies. The case study confirms the importance of:

- **Sharing knowledge** so that others can build on what has been achieved and institutions can apply appropriate methods and results to inform national policy.
- **Capacity building** to maintain and develop GIS and remote sensing modelling systems.
- **Capacity building** to develop skills in remotely sensed data processing and analysis to feed GIS models.
- **Emerging technologies** and open data remote sensing policies from international partners can enhance opportunities to apply spatial technologies for DRM.

Gulf of Mexico and the Caribbean

Aquaculture is increasingly being considered as an alternative to traditional subsistence and commercial capture fisheries in the Gulf of Mexico and the Caribbean region. Coastal managers and aquaculture farmers must simultaneously consider shifts in environmental conditions and oceanographic patterns, possible increases in coastal nutrient pollution, ocean acidification, and the complex interactions of these factors, amongst other stressors.

Types of disasters and the role of spatial technology

The Gulf of Mexico and the Caribbean are disaster-prone areas because of their geographical location and exposure to extreme weather events, high levels of industrial and transportation activities (that increase the risk of technological disasters) and remoteness (Caribbean). The region’s aquaculture operations face a wide range of hazards, including droughts, earthquakes, floods, severe storms, tsunamis (predominantly portions of the Caribbean), tidal surges, transboundary aquatic animal disease, pest outbreaks, landslides and chemical hazards (e.g. oil spills).

On average, a major storm or hurricane makes landfall in the Gulf coast once every two years and every year in the Caribbean, translating into much-needed aquaculture resilience in both regions (OAS, 2001; Landsea *et al.*, 2010; NOAA, 2015). A multitude of spatial technologies are used in the Gulf region during severe storms for all stages of DRM. For instance, to monitor and predict storm surges in the Gulf of Mexico, the United States Geological Survey

(USGS) has a network of highly accurate storm surge pressure sensors consisting of more than 138 pre-surveyed receiving brackets installed along the Gulf coast from Texas to the Florida Keys (USGS, 2018). This allows for rapid deployment of these data gathering instruments in advance of a major hurricane or coastal storm to provide decision-makers with better estimates of flood impacts, assessment of flood damage, and to better distribute assistance to impacted communities.

Climate change poses a number of challenges for aquaculture because of ocean acidification, changes in sea temperatures and circulation patterns, the frequency and severity of extreme events, and sea level rise and associated ecological changes. Ocean acidification can reduce shell thickness and survival in shellfish hatcheries (Mackenzie *et al.*, 2014). Changes in water temperature and flow regimes can diminish water quality, alter growth rates and increase the incidence of disease (Kent, 1992; Noga, 2010; Kim *et al.*, 2017). Increases in the frequency and severity of extreme storm events can cause complete destruction of aquaculture operations, and diminish their ability to recover over time.

High-resolution satellite observation data and an ensemble of climate model simulations are required to fully understand climate impacts within the region. These approaches are utilized widely, not only for aquaculture, but for many ocean activities.

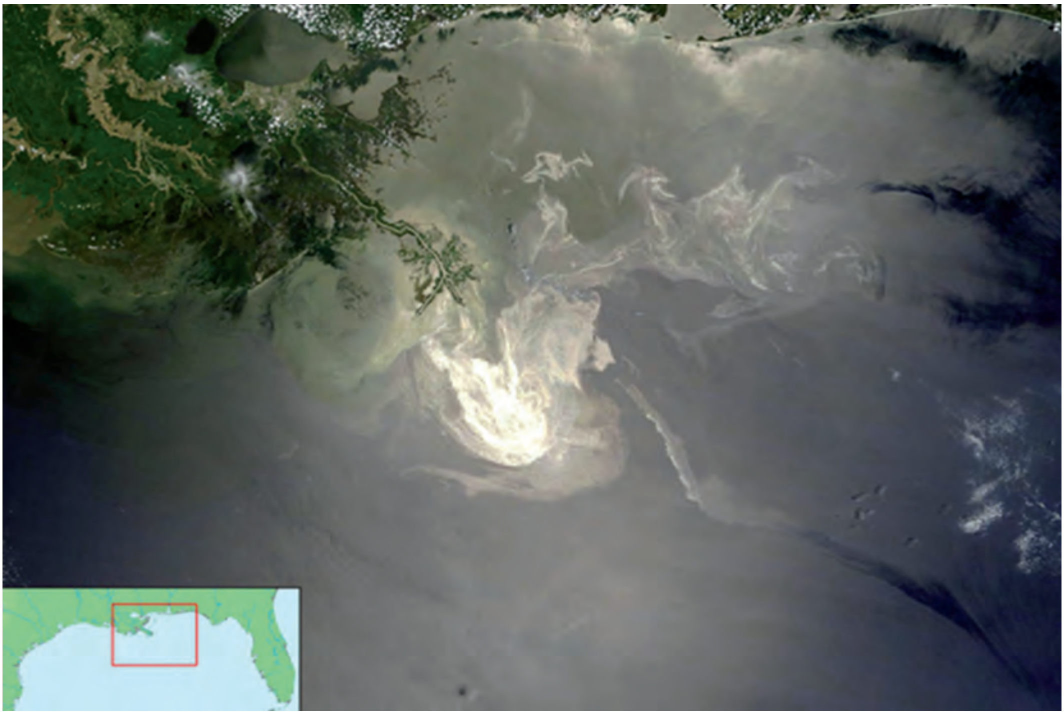
The Caribbean is tectonically active and tsunamis, as well as a number of related hazards, threaten the coast where aquaculture may take place. For instance, landslides occur due to tectonic activity, particularly on some Caribbean islands, and heavy rainfall and flooding can potentially affect processing facilities, markets, homes and livelihoods. Spatial technology can be used to generate landslide susceptibility maps to mitigate some of these impacts.

Biological hazards include disease outbreaks, hypoxia, nutrient loading and harmful algal blooms. Multi-spectral satellite remote sensing data can detect increases in phytoplankton biomass, with harmful algal blooms being distinguished through ecological associations (e.g. nutrient loading, oceanographic conditions, time of year, geographic location).

Technological disasters include industrial accidents, collapse of industrial infrastructure, and transportation. The Deepwater Horizon oil spill in the Gulf of Mexico in 2010 provides an example of the use of optical and radar satellite instruments to track the movement of the oil slick on the ocean surface.

Figure 2 shows the Deepwater Horizon oil spill on 24 May 2010, as it spreads across the Gulf of Mexico. Satellite imagery aided response efforts by determining the direction and extent of the slick, and where immediate environmental emergency response was needed.

FIGURE 2 **This image taken by the NASA Terra satellite shows the oil slick caused by the Deepwater Horizon accident on 24 May 2010. The oil can be seen spreading across the Gulf of Mexico from the compromised drilling site.**



Source: NASA (http://earthobservatory.nasa.gov).

Recommended steps for using spatial technology

DRR:

- The Gulf of Mexico has a vast number of spatial resources for DRR, including sensor systems and forecasting for severe storms and tsunamis, detection of harmful algal blooms, storm surge monitoring and modelling, and a preparedness strategy in place for government and non-government interagency coordination.
- Preparedness includes identification of vulnerable areas (e.g. the Environmental Sensitivity Index maps of the United States National Oceanic and Atmospheric Administration [NOAA]) before a disaster such as an oil spill occurs in the Gulf of Mexico, and defining which areas are most vulnerable to a disaster to improve resource allocation. If aquaculture is in the path of a spill, with enough advanced warning, operations can be relocated to avoid direct impacts.
- The Caribbean region has fewer resources to contribute towards spatial technologies because the Greater and Lesser Antilles contain islands with a mix of socio-economic conditions (e.g. high rates of unemployment and/or income inequality) (Whitemarsh and Palmieri, 2009). However, networks of organizations involved in satellite-based emergency management collaborate to provide the region with severe storm forecasting and tsunami warning systems.

Response:

- Given the vast spread of the region and the remoteness of many locations within it, satellite and drone remote sensing are well-suited for emergency response. Additionally, underwater sensor technologies and ROVs can be used to inspect aquaculture gear in a post-disaster situation, giving managers immediate information for priority actions.

Recovery and rehabilitation:

- Remote sensing information and gridded maps of the impacts of a disaster are vital inputs for planning recovery and rehabilitation efforts. For aquaculture, pre- and post-disaster maps, spatial modelling, and a detailed response and recovery plan allow for planning to reduce or prevent the extent of future damage from another disaster event (e.g. loss of cages in a severe storm).

Conclusions/lessons learned

Collaboration and coordination between government and non-governmental agencies is crucial to prepare for and respond to disaster situations. For coastal and marine aquaculture, this includes preparedness plans for the farm; monitoring for water quality, damaged gear, disease, and escapes; and a recovery plan for a variety of disaster events. In the United States of America Gulf of Mexico, the Coast Guard works with other federal and state agencies to communicate important and timely information so that farm operators can initiate recovery efforts and make prevention plans as soon as possible post-disaster.

The multinational Caribbean Disaster Emergency Management Agency requires each participating island nation to establish or maintain a National Disaster Office. These offices coordinate with other member states to collect the necessary data to aid in recovery efforts.

Objective spatial analyses are needed to determine site suitability, i.e. the areas with the highest suitability and lowest risk from certain defined disasters if the necessary parameters are included, such as climatological averages, maximums, minimums and variance of significant wave height, current speeds, temperature, salinity and harmful algal bloom frequency and toxicity.

Aquaculture development in this region should consider the local ecosystem, ensuring that practices benefit the farm and are not deleterious to other farms or the ecosystem. Responsible siting and practices also require consideration of other ocean sectors, policies and goals, and current and future use patterns.

Strengthening of institutional awareness and education related to spatial technologies (e.g. GIS, drone pilots) for disasters in the Caribbean are key to the coordinated success of aquaculture in planning for and responding to disasters in this region. Having qualified and knowledgeable personnel and spatial tools for each stage of DRM, is essential.

Furthermore, promoting participatory management and shared responsibility for aquaculture DRM must be part of the community structure. To enhance adoption of DRM techniques for aquaculture by communities, including strategic plans, spatial inventories and modified common practices, the entire community must work together to improve resources and adapt to changes for the good of current and future generations.

Indonesia

The archipelago offers exceptional natural conditions for, especially, marine aquaculture; the country was the world's third largest producer of finfish farmed in saltwater in 2016, next to China and Norway (FAO, 2018c). The Government plans to increase production to meet food security and job creation targets.

Types of disasters and the role of spatial technology

Indonesia's location limits its exposure to tropical cyclones, but it is highly vulnerable to a range of natural, technological and complex disasters including:

- **Floods, drought and climate change** that affect water supply and coastal conditions.
- **Geophysical disasters** such as earthquakes, volcanic eruptions and tsunamis.
- **Biological disasters** such as harmful algal blooms that cause major losses to marine fish cage culture.
- **Technological disasters** including pollution from oil production and transportation, and chemical pollution.

Indonesia has implemented a range of technologies, including spatial technologies, to support DRM.

Numerous meteorological stations, in conjunction with satellite receiver systems, operate throughout Indonesia. Predictions of strong winds and significant wave heights for the entire archipelago are made available to the public by the Agency for Meteorology, Climatology and Geophysics of Indonesia (BMKG) several times a day, but these are not necessarily used or understood by the majority of aquaculture farmers.

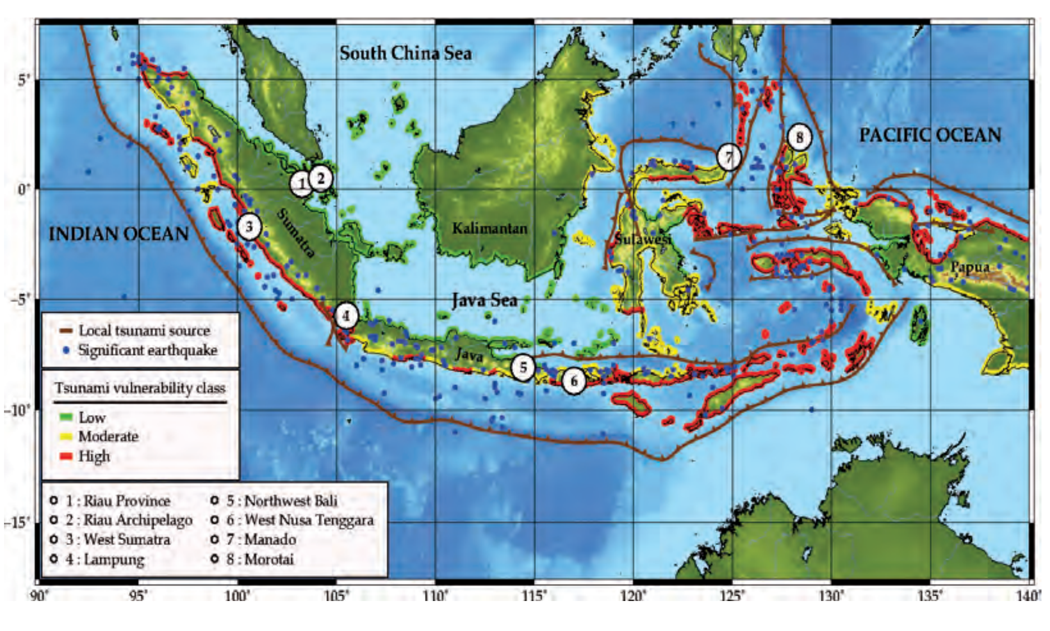
Tidal gauges operated by the Geospatial Information Agency (BIG) monitor water levels across the country, with eleven buoys integrated within the Indonesian Tsunami Early Warning System (InaTEWS), developed in the framework of the joint German–Indonesian cooperation project.

Some marine fish cage culture sites in Indonesia are equipped with monitoring systems for water temperature and salinity and water flow and wave model simulations have been used effectively in the management of marine fish cage culture sites. For example, in Pegametan Bay, Bali, a model with a spatial resolution of about 25 m to 50 m accurately captured current velocity and direction induced by tides, winds and waves and was used for the siting of fish farms and for estimating carrying capacity (Niederndorfer, 2017; Mayerle *et al.*, 2017).

High rainfall and runoff rates in coastal areas can lead to drops in water temperature and salinity, causing stress to cultured fish and increasing their susceptibility to disease. Deforestation and waterways clogged with detritus can also cause severe flooding, transporting debris and high concentrations of silt and affecting onshore culture and coastal operations.

Figure 3 shows the location of the major tectonic faults across the Indonesian archipelago. The resulting tsunami risk levels for the coastline are also indicated. Green, yellow and red coastlines represent coastal areas that are susceptible to low, moderate and high risk of tsunamis, respectively. The location of currently operating marine fish cage culture sites are indicated by the numbered white circles. Sites facing the Indian Ocean (sites 3 and 4 and site 6, Ekas Bay) and the Pacific Ocean (sites 7 and 8) are at high risk of tsunamis.

FIGURE 3 **Sources of tsunamis, location of main earthquakes and tsunami risk levels in Indonesia**



Source: Courtesy of Research and Technology Centre Westcoast, University of Kiel, Germany.

Recommended steps for using spatial technology

DRR:

- Use spatial technologies to identify aquaculture sites with lower exposure to hazards.
- Use the available operational services from government agencies for early warning.
- Invest in capacity building of local communities to guarantee quick reactions after severe storm and tsunami events.
- Equip sites with operational monitoring systems for early warning.

Response:

Use remote sensing to assess impacts and emergency needs, given the vast extent and remoteness of many parts of the Indonesian archipelago.

Recovery and rehabilitation:
Remote sensing techniques can support management measures and interventions to recover and rehabilitate an aquaculture site damaged by a disaster event.

Conclusions/lessons learned

The available spatial technologies for early warning and preparedness have not been widely and thoroughly used for DRM in aquaculture.

Expanded use of spatial technologies depends on: government policies, awareness of the benefits of spatial analysis, allocation of financial and human resources and equipment, and experience in spatial analysis.

In view of the government's policy to expand aquaculture, the integration of spatial technologies into broader DRM initiatives, preferably the national DRM strategy, is required.

The use of advanced technologies and methods should be intensified, and agencies involved in DRM should extend the range of their applications to marine aquaculture.

Specific recommendations:

- Use spatial technology to anticipate, prevent and reduce the impact of disasters, to the extent possible.
- Integrate spatial technology for DRR in recovery to reduce future risks.
- Promote awareness of new spatial technology applications for aquaculture.
- Build capacity of people and institutions in the use of spatial technologies.
- Strengthen cooperation between agencies and ministries, non-governmental organizations (NGOs), academia, the private sector and communities to enhance DRM for aquaculture.
- Intensify cooperation among the countries of the Association of Southeast Asian Nations (ASEAN). Early warning of tropical storms, oil spills, tsunamis and the assessment of the impacts of climate change should be coordinated between ASEAN countries.

9 . Policy support needed

Spatial technologies provide a reliable basis for policy and governance for DRM in the aquaculture sector. Policy support is required to promote the adoption of spatial technologies.

A strategy to promote the use of spatial technologies for DRM is recommended. The strategy needs adequate and appropriate policy measures for effective execution. The major areas for policy support include:

Institutional strengthening and regional coordination

Strengthening of institutions and regional coordination are key to the coordinated success of aquaculture in planning for, and responding to, a disaster. Personnel trained in spatial sciences and aquaculture are essential for the efficient implementation of spatial technologies for DRM within the aquaculture sector.

Coordination of emergency preparedness and response needs to be led by a competent lead agency (or key agencies). This will help to coordinate partners and ensure the timely and efficient use of technologies relevant to aquaculture.

Communication and early warning

Maintenance of spatial technologies and emergency response plans by responsible organizations is critical. Many disaster events occur in short time periods, which requires rapid analysis and warning. Investments in early warning systems must include a commitment to maintenance and testing. For instance, because of non-functional sensor systems, little or no warning was given for the tsunami that struck Sulawesi, Indonesia in September 2018 (BBC, 2018c). Damage to aquaculture infrastructure is often unavoidable in a tsunami, but sensor systems can warn people to leave the area before the tsunami strikes, preventing major loss of life.

Partnerships and networks

Building capacity requires reaching out to and forging links with many small, globally dispersed audiences involved in aquaculture. This in turn requires a broad strategy that takes advantage of common interests and synergies in the DRM principles and objectives that are shared by national and international agencies, entrepreneurs, NGOs and private companies.

Technology transfer

A wide range of spatial technologies are available and relevant to DRM for aquaculture. Most can be adapted and made available to local communities, governments and international agencies to support DRM.

Capacity building

Technical capacity is essential and more efforts to provide technical training and capacity building are needed. This Guide provides a framework for developing experience and expertise in spatial technologies, with reference to training sources.

Spatial data to support DRM

Some regions have vast quantities of spatial data freely available that are important for use in spatial analyses in support of DRM. Those regions that are data poor, can still use remote sensing data (e.g. free desktop software such as Google Earth) and analyses to support DRM for aquaculture.

Essential steps for implementing spatial analyses in support of DRM at national level would be to inventory and evaluate aquaculture and DRM-relevant spatial data at available resolutions (e.g. the number, type and location of aquaculture facilities; pre- and post-disaster imagery). The Internet is the most rapid and efficient pipeline for wide-ranging technical assistance, for the exchange of data and to communicate in support of DRM.

Often, data can be requested and obtained from public entities because many climatological data sets are too large to host on the Internet. These larger datasets are available at the global scale and are available, for example, from NOAA's World Ocean Atlas (https://www.nodc.noaa.gov/OC5/indprod.html).

Integrating DRR into spatial planning for aquaculture

Aquaculture zoning, site selection and area management (Brummett, 2013; FAO and World Bank, 2015; Aguilar-Manjarrez, Soto and Brummett, 2017) include the evaluation of multiple hazards. Aquaculture scenario planning needs to be integrated into DRR strategies.

Spatial planning helps to identify the most suitable aquaculture sites – those that have the lowest area use conflict, good culture conditions for the species, are located away from environmentally sensitive areas, have low relative disaster risks and are amenable to appropriate monitoring.

Most of the major threats to aquaculture have a spatial dimension and can be mapped. Risk mapping helps to identify the more serious threats.

Effective spatial planning improves resilience and establishes an aquaculture sector that is well prepared for the potential impacts of disasters. It creates effective mechanisms for governments and other institutions, including civil society organizations, to deliver services and fulfil their commitments to sustainable aquaculture development.

Spatial inventory of aquaculture operations at subnational and particularly at the individual farm scale is necessary for spatial planning efforts (Ottinger, Clauss and Kuenzer, 2017).

Knowledge of the distribution and characteristics of farming systems requires, at a minimum, information on cultured species, culture systems and production, and other factors such as the existence of monitoring and sensor systems used to improve the effectiveness of spatial planning and risk management.

Gender and spatial technologies

Spatial technologies are often considered gender neutral – in other words, men and women have the same ability to access, use and control these technologies. As with ICTs, this is often far from the case, because women generally are not trained in these technologies and are usually more involved in the processing and marketing of aquaculture products (FAO, 2018d). Learning from research in the agriculture sector (as well as the Gender in Aquaculture and Fisheries Forum), practitioners should conduct a gender analysis to describe where and how men and women participate in the specific value chain or aquaculture activity (including DRM). It is critical that initiatives seeking to improve gender equality and equity target the family unit and the community. A family-centred or community-centred approach will help to foster widespread recognition of the importance of both men and women understanding spatial technologies and their applications.

Incentives and disincentives

Incentives are important for the establishment of farms in designated areas and sites that are less exposed to hazards. Farms that participate in area management protocols and operate with environmentally sound practices and biosecurity measures, should be given incentives. And disincentives need to be applied for non-compliance with the aforementioned factors, particularly if poor farm practices cause harm to other farms in the same established area, or render the area unusable.

Building and maintaining the capacity to implement spatial technologies

The success of spatial technology in support of DRM depends on interest, finances and capacity. There is a need to identify, qualify and quantify spatial analysis capacity at the country level in order to match training and technical support and the capacity to absorb them.

Sufficient and timely release of funds is required to build capacity and enable the acquisition of relevant spatial technologies (e.g. GIS software, remote sensing imagery and carrying capacity models). The funding level will depend on risk and needs on a case-by-case basis. There is a range of cost options to choose from.

Technical support can be obtained from an array of sources, such as specialized agencies, private companies and international experts.

Implementation of spatial technologies for DRM in aquaculture requires appropriate regulations, including those that facilitate shared access to essential data and information. An effective DRM process should be participatory and exploit the best available knowledge, which should include local interests and stakeholder knowledge.

Finally, it is emphasized that this set of policies, which includes a legal and institutional framework to support and encourage the sustained use of spatial technologies, can only be developed and then adhered to with constant communication and consultation among the major stakeholders.

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.

Annex 1. Disaster response information and data portals

TABLE 1 **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 2 **Hazard and risk models and statistics**

Name	URL
International Charter "Space and Major Disasters" map of past activations (major disaster events)	https://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

The FAO *Guidance on spatial technologies for disaster risk management in aquaculture* includes three annexes on (i) Spatial data and data products; (ii) Data portals; and (iii) Technical support and training.

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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.

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