Response considerations when marine spills affect coastal agriculture

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ABSTRACT

Agriculture can also be an integral economic activity to many coastal communities, but the vulnerability, and sensitivity, of this sector to marine oil spills is not well documented or understood. In ITOPF's experience, oil spills affecting agriculture are less common than those that impact fisheries and mariculture. As a result, knowledge and capability to effectively respond to cases when agriculture is a key vulnerability, are frequently lacking. Many agricultural activities are wholly land-based and not dependent on the interaction between the land-sea interface. As such, they are buffered and unlikely to be directly impacted by oil spills. However, in many countries around the world, tidal agriculture is an important contributor to the economy, closely dependent on the intertidal zone at the land-sea interface, and these industries can be highly vulnerable to oil spills. Specific activities that have been considered as tidal agriculture for the purpose of this paper include; salt production, rice cultivation and the rearing of high value/speciality livestock (e.g. salt marsh lamb).

In almost fifty years since ITOPF's establishment, a number of cases attended on site have involved tidal agriculture as a key vulnerability that has influenced the nature and direction of a response. A review of these cases has shown some recurring themes in the main considerations and challenges associated with clean-up and impact mitigation. Using case studies of oil spills ITOPF has attended in Asia, Europe and South America, this paper will discuss these key considerations in turn, and describe, through the case studies, how they were resolved or addressed. This paper will also summarise the findings to provide general guidance for responding to oil spills where tidal agriculture is an important industry.

INTRODUCTION

For almost as long as there has been one, the oil spill response community (including ITOPF, in its almost 50 years' experience in oil spill response) has recognised that marine oil spills can and sometimes do significantly disrupt the wild fisheries and mariculture production sectors. Less frequently affected, and therefore not often associated with marine oil spills are coastal agriculture activities. For example, a search of keywords from abstracts presented at IOSC over the years, shows that the term "fisheries" appears in 373 abstracts, with "mariculture" or "aquaculture" appearing in 22. By contrast, "agriculture" has appeared in only 12 IOSC abstracts. In this paper, "coastal agriculture" has been defined as land based agriculture that occurs in proximity to the coast and that is in some way influenced by or dependent upon the conditions provided by the interface between the sea and the land. The extractive use or harvesting of coastal resources has not been included. In many parts of the world, particularly along deltas, coastal floodplains and on Small Island Developing States (SIDS), coastal agriculture is as important to the local economy and/or food supply as fisheries and mariculture. Simultaneously, it is increasingly under threat from multiple, chronic stressors such as high human population densities, climate change, erosion, terrestrial source pollution and conflicting uses for space (FAO, 2008). Although not widely reported, when oil spills do threaten or impact upon coastal agriculture activities, the implications both in terms of response challenges and effects can be complex. These complexities are due to the highly specialised nature of the environment (which can either be natural or may have been historically engineered to create a unique habitat), the lack of alternative options for income, and the often artisanal and/or high added value nature of the associated products.

According to Scialabba (1998), there are several benefits to agriculture associated with coastal and riparian areas that more inland areas are not subjected to and that were key historical drivers for the development of agriculture. These include;

- Alluvial plains, deep, relatively flat and fertile soils;
- A regular supply of water, and;
- Milder or less variable climate than inland.

However, these benefits also coexist with threats that are inherent of the coast. For example the coast exposes crops and infrastructure to a greater frequency and severity of physical disturbance caused by storms and extreme weather. Low elevations are subject to a greater degree of flooding, and drainage can be poor (Morton, 2002). Finally, the periodicity of saltwater inundation, either periodically induced by the tides or exceptionally by extreme weather can be destructive to terrestrial crops. However, this phenomenon is also a determinant for the persistence of more specialised agriculture (i.e. salt harvesting, supporting rice paddy irrigation, and the provision of saltmarsh for grazing). The benefits provided by coastal conditions on agriculture are, by definition, spatially limited (Scialabba, 1998). Despite these physical pressures, the benefits in productivity usually outweigh these risks and coastal agriculture is frequently characterised by long established, traditional and adaptable practices, which have changed little in hundreds of years, from when they were first pioneered to take advantage of the favourable conditions. In some cases, coastal engineering undertaken a millennium ago, created the conditions that support the agricultural activities still prevalent to this day. Various types of coastal agriculture that share these deep-rooted practices and are dependent on historical engineering, can be encountered all over the world and can raise consistently similar issues and challenges during an oil spill. Table 1 provides an overview of specific coastal agriculture activities discussed in this paper.

Table 1 Overview coastal agriculture activities discussed in this paper.

Pastoral farming	Rearing of livestock in coastal areas which primarily involves cattle and sheep. Coastal and floodplain grazing land provide rich foraging material to fatten livestock, especially over the summer months. Salt marshes are considered to be habitats of critical ecological significance, supporting diverse assemblages of wading and migrating birds. Many saltmarshes in Europe and North America are products of ancient tidal flood defences, constructed to protect this grazing space. For example In the UK, there is evidence that coastal marshes in Essex were engineered to be used as sheep pasturage from at least the late Saxon period (Gascoigne and Medlycott 2014).
Salt production	Sea salt has been produced by evaporation using solar energy since prehistoric times. Salt has been a key commodity to humans for thousands of years to the point it was considered a form of currency by certain peoples. Salt's ability to preserve food was a founding contributor to civilization and helped to eliminate dependence on seasonal availability of food. Salt production ponds are usually found along low-lying sheltered shores characterised by a combination of steady warm temperatures, low precipitation and coastal winds which create an ideal environment for harvesting sea salt (see Kurlansky, 2002).
Rice cultivation	Rice is a semi aquatic, annual grass and one of the World's most important crops and ranks second in terms of area and production volume (Virk et al. 2004). It grows on every continent (with the exception of Antarctica) and under a wide range of water regimes and soil types. Approximately 95% of the world's rice is produced in either irrigated or rain-fed lowland systems. While much irrigated rice production is done using traditional technology, changing water availability means that the technology in this field is rapidly changing and evolving and there are currently multiple techniques and systems in use.

The majority of oil spills from ships occur within close proximity to the coast. Of the 703 incidents ITOPF has attended on site around the world, during the active phase of the response 501 (79.5%) have occurred within 10nm of land, and 72% have occurred within 5nm (Figure 1).

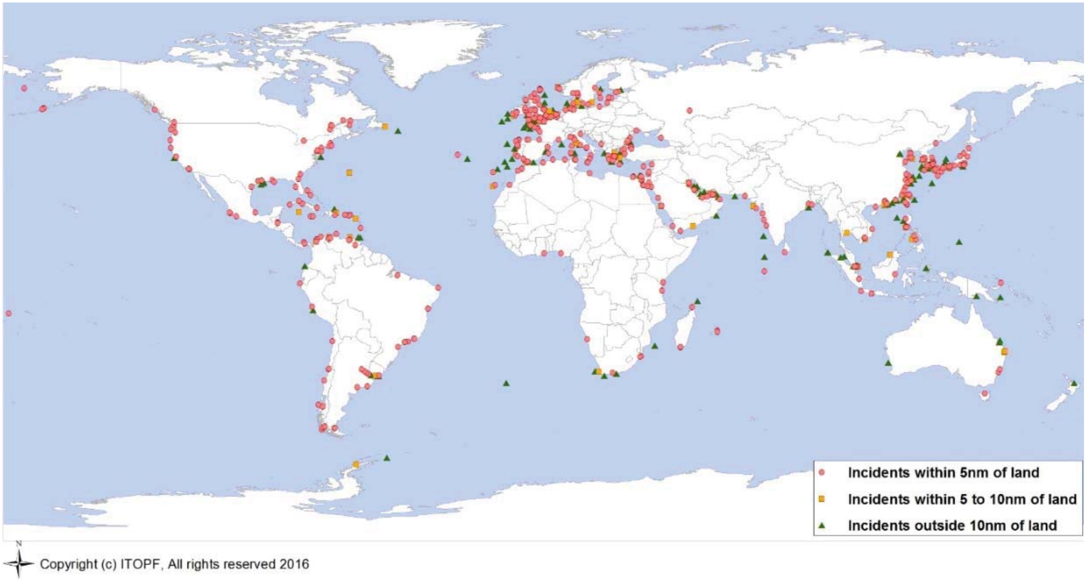

Figure 1. The locations of ITOPF attended incidents since 1969, and their distance from the coast.

Over the years, ITOPF has attended a number of cases where coastal agricultural activities have been threatened or impacted by oil spills at sea or by subsequent response operations. While various best practice guides on preparedness and response to marine oil spills acknowledge that coastal agriculture may be one of the key sensitivities (e.g. ITOPF TIPs) in an area affected by an oil spill, agriculture-specific guidance on mitigation measures and best practice approaches are generally lacking.

This paper highlights the agriculture-specific considerations that were encountered during one particular recent case involving irrigated rice cultivation in Japan. Given the commonalities in the themes of the key issues, this example is supported throughout by two well-documented, high profile historical cases that involved traditional salt harvesting and pastoral farming, respectively. The mechanisms by which oil spills and associated response efforts affect coastal agriculture have not been as well documented or reported as ecological or fisheries concerns. This can be attributed to a number of factors. Foremost, in the authors' experience, coastal agriculture facilities based on land or intertidal zones that are often protected by sea defences, tend to be impacted less frequently than activities physically taking place within the marine environment. A second factor may also be that the primary focus in the aftermath of an incident is the potential for the incident to have a detrimental impact on the environment, whereas agricultural activities, being largely highly managed, tend to be considered outside of this scope. Notwithstanding the fact that coastal agriculture is impacted less frequently by oil spills, when it is, the consequences of inadequate or limited activity-specific planning can lead to worse impacts than for more vulnerable or commonly affected activities in the affected area. This paper will show that across three different types of coastal agriculture, there are trends in the challenges encountered during three well documented cases. These similarities have implications for how agriculture-related impacts could be mitigated in future spills if they are specifically addressed at each stage from the planning phase, through to the response, post-spill recovery phase and claims and compensation.

DISCUSSION

1. Case studies

Sakata City on northern Honshu Island, Japan is located on the coastal plains of Yamagata Prefecture. The climate is humid subtropical, with hot summers and cool winters. The coastal plains are typically snow covered between early January and March. The City has approximately 100,000 inhabitants and is economically reliant on light industry, fishing and agriculture. The coastal floodplains are used for the irrigated cultivation of several rice varieties, including the premium *Tsuyahime* rice via a network of channels that was constructed in the 1950s. Water from the snowmelt in the nearby mountains is transported along the Nikkofuru River to the north of the Sakata City rice paddies. A network of channels, primarily organised along an elevation gradient cause the paddies to progressively fill with water. At the end of the cultivation cycle, the paddies are drained through channels into the Yutaka River to the south, assisted by mechanical pumps (Figure 2), and the crop is harvested. When full, the water is prevented from draining by sluice gates at each drainage channel. The annual rice crop is sown towards the end of March and harvested throughout the month of October. Rice production in Yamagata Prefecture is the fourth highest of all prefectures in Japan with an output of 415,000 tonnes in 2012. There are 67,900 ha given over to rice paddies within Yamagata[1] and the area around Sakata City is cited as one of Japan's primary rice growing areas.

On 10th January 2016, a general cargo vessel ran aground on the breakwater at the entrance to the Port of Sakata. Due to prolonged heavy swell conditions, Heavy Fuel Oil (HFO) IFO180 spilled from the vessel's fuel tanks when they broke apart and was transported over the breakwater by waves, into the port, and 4km upstream of the Yutaka River, depositing as 30cm bands (2-4mm thick) along both sides of the concrete and reed covered riverbanks. Immediately following the stranding of oil, there was the first heavy snowfall of winter, which persisted for the subsequent two months.

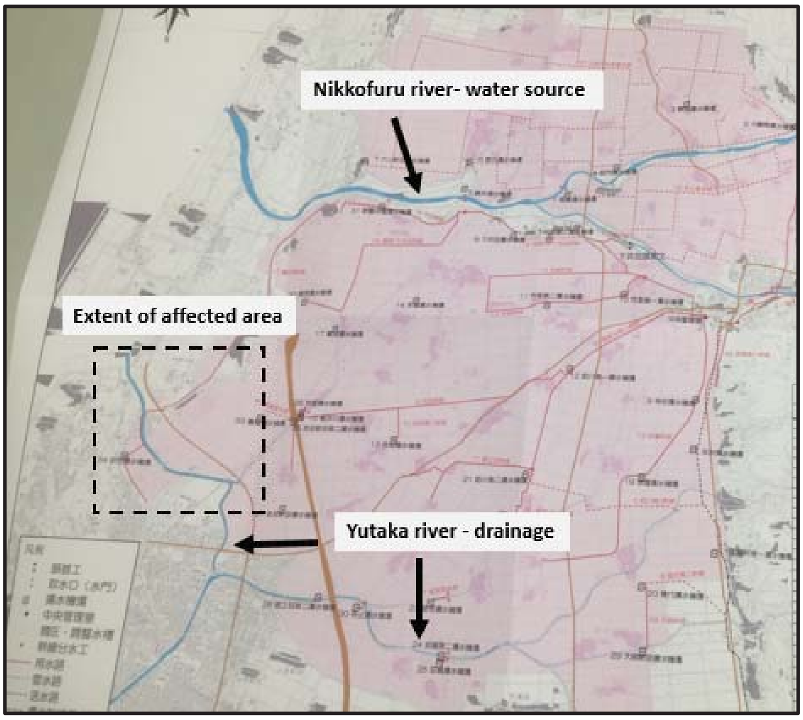

Figure 2 Blueprints for the Sakata City rice paddy network.

At the time of the incident, as the rice paddies were lying fallow and were drained,

[1] Data from the Ministry of Agriculture, Fisheries and Forestry: http://www.maff.go.jp

some of the sluice gates of the drainage channels had been left open and oil was transported through the drainage channels during exceptionally high water levels, staining the upper edges of the concrete channels, around the edge of the rice fields. In all, approximately 2 km of channels were oiled. ITOPF's attendance was requested to assist with the unique nature of the contamination and the first author arrived on site on 19th January. Clean-up of the riverbanks and drainage channels had yet to commence, although the majority of free floating bulk oil and oiled debris had been recovered by this point. Further response included the following:

1. Manual removal of oiled reeds and vegetation along 8km of riverbank. Electric tools were trialled initially but were unselective and created greater quantities of oiled debris;
2. Manual removal of vegetation along drainage channels around the outer edge of rice paddies;
3. Hot water, high pressure washing along 8 km of riverbank. The authorities were more concerned with aesthetics than environmental issues and therefore the acceptable end point was - no layer of "scrapable" oil to be left, and visible stains to be reduced as far as possible;
4. A combination of scrubbing residual stain off drainage channels with degreaser and wire brushes, followed by hot water, high pressure washing. The acceptable end point was no visible stain. Food quality standards in Japan are exceptionally high and any public perception of the spill having affected the rice paddies would have resulted in markets not accepting the premium rice.

Two high-profile and well documented cases which featured prominent agricultural concerns and have been used throughout this paper to support the considerations highlighted in the case from Sakata City are summarised in table 2.

Table 2 Summary of BRAER and ERIKA case studies. Agriculture-specific issues are highlighted in subsequent sections of the paper.

Case Study	Details	Agriculture
BRAER, Shetland Islands, UK, December 1993	Following engine failure, Liberian tanker BRAER ran aground in severe weather conditions on Garth's Ness, Shetland on 5th January 1993. Over a period of 12 days the entire cargo of 84,700 tonnes of Norwegian Gullfaks crude oil, plus up to 1,500 tonnes of heavy bunker oil, were lost under severe weather conditions. Weather conditions prevented the use of mechanical recovery equipment at sea, although about 130 tonnes of chemical dispersant was applied from aircraft during periods when the wind abated slightly and some oil remained on the surface. Oiling of shorelines was minimal relative to the size of the spill and clean-up involved the collection of oily debris and vegetation. A combination of the light nature of the oil and the exceptionally strong wind and wave energy naturally dispersed most of the oil throughout the water column with a smaller proportion transported aerially as droplets and contaminating 6,000 ha of clifftop grassland with oil droplets	Pastoral farming- cattle and sheep
ERIKA, Brittany, France, December, 1999	The Maltese tanker ERIKA, carrying some 31,000 tonnes of heavy fuel oil as cargo, broke in two in a severe storm in the Bay of Biscay on 12th December 1999, 60 miles from the coast of Brittany. About 20,000 tonnes of oil were spilled. Owing to the influence of strong winds and currents, shoreline oiling did not occur as quickly as expected or in the locations originally forecast. After first moving south-east from the spill site toward La Rochelle, then turning north, the oil finally began stranding heavily around the mouth of the River Loire on Christmas Day 1999. Intermittent oiling subsequently occurred over some 400km of shoreline between Finistère and Charente-Maritime. Due to the long time that the oil spent at sea, much of it formed a water-in-oil emulsion, which significantly increased its volume and viscosity. The degree of oiling of shores was very patchy through the affected area. The most heavily contaminated areas were located in Loire Atlantique, the northern Vendée and on offshore islands, notably Belle-Ile. These areas required the mobilisation of considerable clean-up resources to carry out a programme of initial bulk oil removal, followed by prolonged and difficult secondary cleaning. Other areas received only very light oiling (e.g. parts of Finistère and Morbihan) where fine cleaning alone was needed. Shoreline clean-up operations were finally concluded on April 2001 with the dredging of a sunken and buried oil slick affecting oyster and salt production areas.	Traditional salt harvesting

2. Response considerations

2.1 Seasonality and cultivation cycles

The timing of an oil spill can have a significant effect on the extent to which coastal agriculture is likely to be affected, especially in temperate regions. This in turn affects what the most appropriate treatment options and end-points will be. Following the incident in

Sakata City, prolonged and heavy snowfall caused considerable disruption and delay to the progress of clean-up operations. The completion of clean-up operations prior to the thaw, which takes place between the first and third week in March was essential to ensure that farming operations would not be affected by either the oil or the response operations. This resulted in the use of more aggressive clean-up techniques being employed than would normally be used in a river system. Residual stains along the rice paddy channels and riverbanks were treated with hot water, high pressure washers, at the request of the authorities. A total of 8km of concrete riverbank were treated in this way. Such treatment would not normally be advised for an ecologically sensitive and structurally vulnerable area (the channels and riverbanks had been constructed over 70 years earlier). Ultimately, however, the authorities requested that farming activities be prioritised and despite slow progress caused by the weather, clean-up was completed on time and to the satisfaction of the authorities.

The salt pans of the Guérande in southern Brittany also operate along a similar yearly cycle, with salt production driven and regulated by insolation, temperature, wind and precipitation. Salt production generally occurs between mid/late March, through to October, weather depending. A spill of similar magnitude as the ERIKA during the spring or summer, therefore, could have resulted in all production that year being cancelled. A spill occurring in autumn would have allowed the greatest period of time for clean-up operations and natural recovery. The spill occurred in mid-winter, which allowed some time for response operations to remove the majority of oil. However, the sheer scale of the oil spill and the issues associated with periodic remobilisation ultimately affected some of the salt production areas. Ultimately, the presence of oil in the vicinity of ponds led to two thirds of the producers that were grouped in a cooperative, to halt production in the season following the spill.

In the case of the BRAER, the occurrence of the incident during winter was a factor that was found to be partly responsible for mitigating impacts to livestock (Milne *et al.*, 1997). Of the sheep that were outwintered, none were due to be slaughtered for a period of at least six months. Beef cattle and dairy cows are routinely housed over winter and fed on hay, and therefore there was no disruption to this activity caused by the oil spill. Following the incident, a study determined that there were no long terms effects associated with the wind driven aerial deposition of oil. This was attributed in part to the timing of the incident and in part to the low uptake of polycyclic aromatic hydrocarbons (PAHs) into plant and animal tissues (Milne *et al.* 1997), with sheep selectively feeding on uncontaminated vegetation. A winter oil spill will also have a less detrimental effect on grazed vegetation. During this dormant period, oil would be less likely to have an herbicidal effect, and productivity could be expected to resume relatively normally (Hoff *et al.* 1993, Bayfield and Frankiss 1997).

2.2 Coastal/hydraulic engineering

Following the spill in Sakata City, it took more than two weeks for responders to be provided with a detailed explanation or blueprints of the irrigation channel network for the rice paddies, (constructed in the 1950s). Although the agricultural land is owned and managed by cooperatives of farmers, the network of irrigation channels is managed by a local Prefecture department, and the responsibility for maintenance falls to them. However, over the years, routine maintenance had not required detailed knowledge of the entire system, and therefore as they are so rarely required, personnel at the department could not immediately locate the blueprints. The primary need for responders was to establish whether the channels between the rice fields and Yutaka River were for water intake, as this would have affected clean-up operations along the river bank and the risk of any remobilised oil being transported into the rice fields. Once the blueprints were located, it was determined that the channels along the Yutaka riverbank were solely for drainage, and it became clear that water from the Yutaka would not enter the rice fields. It therefore reduced the need to establish contingency plans and economic impact mitigation measures and alleviated concerns regarding oil from the riverbank remobilising to contaminate the drainage channels.

It should be noted that hydraulic mechanisms for irrigated rice paddies vary substantially, not only by country, but also within countries. The systems in place can often be very old, either mechanically or non-mechanically assisted and in poor states of maintenance. The design and construction of salt pan networks are subject to the same degree of variability.

The salt pans in southern Brittany were constructed over 1,000 years ago, and the mechanism by which they operate has remained unchanged. The networks of ponds and channels (*étiers*) operate entirely by gravity with no mechanical assistance. In some cases water intake is controllable by sluice gates. The initial basin is a large, deep *vasière*, which fills during a spring tide and acts primarily as a water reserve and as a first stage decanter, allowing large suspended solids to filter out. From there, water flows with gravity through a *corbier* - a type of elongated stream to further purify the water and enable increasing salt concentration. This promotes the eradication of seaweeds and burrowing amphipods which would taint the final product and/or damage the production pond structure. From there, water circulates through *fares* which are very shallow ponds, separated by chicanes, encouraging further evaporation. The resulting brine then collects in an *aderne*, which acts as a reservoir of brine for the final stage of production. The concentrated brine then flows into the final pond, (*œillet*) where the salt is harvested (Figure 3).

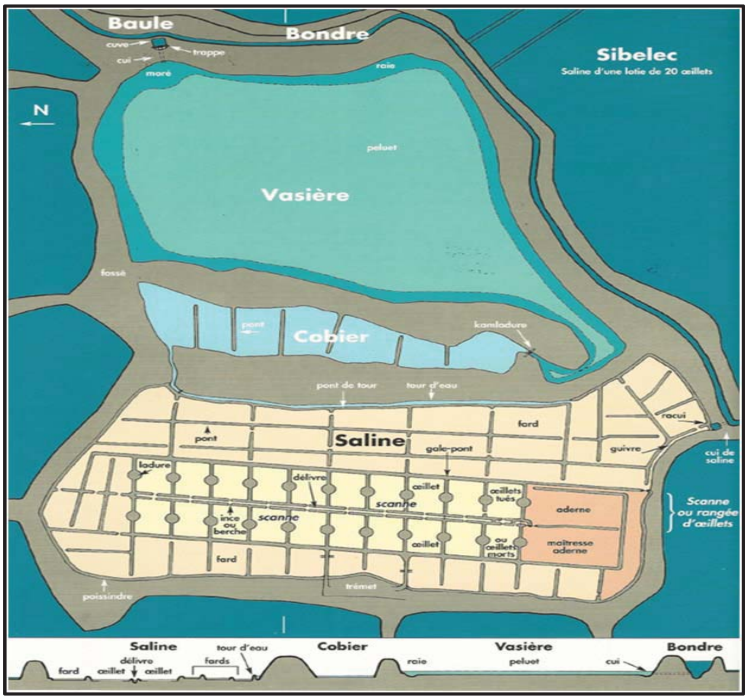

Figure 3 Schematic representation of saltpans from La Guérande. Above: planar view. Below: cross-sectional view.

During the ERIKA, salt harvesters became involved with the work to protect the salt pans from the start, despite it being outside of the production season. Some *étiers* had sluice gates in place, and in these cases, they were closed on 26th December. *Étiers* that were unprotected by sluice gates had filtration barriers erected by the salt producers in liaison with the response command centres and Cedre. Local knowledge was key. At a later stage, filtration boxes were set-up at the water intakes of the most exposed *vasières*.

This example is just one of many potential configurations, and for responders arriving on the scene, it will be impossible to understand the mechanics of the networks. For example, if all channels are inundated on a daily basis, then rapid intervention may be critical to reduce the risk of oil contaminating the network. Alternatively, if seawater inundation occurs only during spring tides, or under mechanical assistance, the risk of contamination, and therefore the urgency to act, may be reduced.

The presence (or absence) of coastal engineering can also affect the ease with which livestock can be confined to reduce potential contamination of the food chain, secondary contamination and to allow contaminated vegetation to recover. For example, during the BRAER oil spill, in the most heavily contaminated inland area (approximately 20 square miles), sheep belonging to 200 crofters were moved, confined and their feed supplemented with previously harvested hay and silage (Gervais, 1997). Sheep were easily confined due to the presence of ancient *crues* (stone walled enclosures built for confining sheep), and this operation did not require additional resources in order to enclose the animals.

To assist responders in their planning, it would be useful for blueprints, diagrams and maps of any hydraulic or enclosure systems or networks used in coastal agriculture to be included in the information section of contingency plans.

2.3 Response / secondary damage

The trade-off between achieving a satisfactory clean-up endpoint without causing further damage to property and or disruption to the environment and economic activities is a fundamental principle of oil spill response in general. The marked seasonality, coupled with the often old infrastructure can potentially make coastal agriculture more vulnerable to aggressive clean-up activities than would otherwise be the case. In the case of the contaminated rice paddies in Sakata City, so as to avoid rutting of the fields, all treatment of the irrigation channels within the rice fields was undertaken manually, including waste transport, due to concerns that high volume traffic of large vehicles would damage the fields before the start of the cultivation period.

The first stage ponds (*vasière*) of the Guerande salt pans affected by the ERIKA oil spill are routinely subject to maintenance requiring the use of heavy machinery. As such, recovery using heavy machinery in these outer ponds would have been appropriate, without substantial risk of causing significant damage. However, during the response, there were few excavator operators experienced with working in the salt ponds and therefore, to avoid the risk of causing further damage to the ponds, most of the response was carried out manually. In some cases, measures to prevent ingress of oil-contaminated water can result in unexpected damage. In the case of the ERIKA spill, makeshift filtration barriers, and later on clay dams equipped with one way valves, were placed across water intake channels to prevent the ingress of oil and oily water. These stayed in place for a year and a half and prevented regular seawater exchange. The resulting freshwater (rain) build up led to some of the ponds becoming infested with the grass *Ruppia spp.* which led to the ponds requiring non-routine maintenance work prior to recommencing salt production. Salt farmers alleged this was a direct consequence of the preventive measure to block water exchange, rather than a problem that could occur even under normal operating conditions. Similarly, stagnant water was cited as causing the burrowing amphipod (*Corophium volutator*) to survive in the shallower ponds, and damage the integrity of these ponds. Eventually, the French courts found insufficient evidence of this being a direct consequence of the preventive measure of blocking intake channels. Furthermore, this action was considered to have been the course of action to take at the time. Ultimately, the farmers were awarded compensation for the additional work they undertook to protect the salt pans from oil and for the loss of salt production in the 2000 season.

Marsh-reared livestock can exacerbate these issues by trampling oil into the substrate, causing it to bury and result in further damage. Unrestricted livestock could act as vectors for secondary contamination, causing previously unoiled areas to become oiled (For inland example, see: Getter *et al.* 2002). Even in the absence of grazing livestock, coastal marshes can be particularly sensitive to the effects of oil spills. The inherently low energy environment, combined with the convoluted surface structure caused by vegetation and an often porous substrate can trap oil, causing it to persist for prolonged periods of time. For this reason, frequently the treatment recommendation for contaminated marshes is to do nothing.

2.4 Traditional and cooperative management

The spatial restrictions imposed by the boundary of the land with the sea, and the elevated population densities at the coast mean that land given over to agricultural land in the coastal zone is often at a premium, with smaller individual plots than would be expected inland, and frequently a greater number of people wanting access to the resource (Scialabba, 1998). As a result, traditional management through cooperatives or private enterprises is more prevalent in the small-scale sector than on large, industrial-scale farms. This system of management is not unique to agriculture and in the authors' experience is most commonly encountered in coastal fisheries and mariculture.

During an oil spill, the organisation of businesses into cooperatives has also frequently been found to be a positive factor. Their management means that annual production can be more easily regulated, that production of surplus is common, and that these can be used to bolster years of reduced demand or yield. In the case of ERIKA, the salt pans were managed in two ways: 1. a well-established cooperative of 200 farmers and, 2. Owned and managed by individuals. Although salt pans remained uncontaminated due to the preventive measures undertaken during the response, the cooperative voluntarily elected not to produce salt that year to protect the high-value image of the artisanal product (whose primary export market is Japan, known for its rigorous food quality standards). Natural productivity rates of salt are highly volatile, and heavily dependent on weather conditions - one œillet produces between 100 kg and three tonnes per year. Therefore, the cooperative normally held surplus stock from previous years to mitigate low production years, and therefore the decision to halt production for one season was viable for the members of the cooperative without major economic consequences. Individual producers however, had no surplus stock, and despite the risks to the image of the product, some decided to continue with salt production for that year, whereas others chose not to. While all were compensated for the losses experienced, the cooperative was far more resilient when faced with an unforeseen disruptive event and was able to consider a variety of options.

For responders and those in charge of managing the incident, the organisation of producers into associations and cooperatives can also be an effective communication tool. By engaging with producers through the cooperative, the dissemination of consistent messages, advice and updates can be achieved, through one trusted channel, reducing the risk for confusion and conflicting information from multiple sources.

The existence of cooperatives also assists in the compiling of claims, and provide an important means of verification for the validity of those claims, thus expediting their settlement and minimising the degree of disruption felt by producers.

2.5 Sampling and monitoring

Chemical monitoring following oil spills began in the 1970s and since then has become an important component in many spills where vulnerable resources are at risk. In particular, chemical monitoring is important where food resources may have been affected by oil, and public safety is a concern. Of the many hydrocarbon compounds of which mineral oil is comprised, PAHs are those considered to be a risk to health and safety, as excessive accumulation in human tissue can lead to cancer (Boffetta *et al.*, 1997). Although PAHs exist at background levels, the primary exposure pathway for humans is through food, and many countries provide guidance on the upper concentration threshold limits for various food items, based on consumption patterns. Whereas the procedures for seafood are well defined, those for livestock and crops are not, which can mean procedures need to be developed on an *ad hoc* basis, during the response phase of a spill.

For example, in relation to the oil spill in Sakata City, ITOPF was able to provide specific guidance on sampling rice for PAH contamination, of which there is limited research and information available, both in general and following oil spills. However, a study investigating the presence of PAH contamination in rice from Tokushima (a city approximately twice the size of Sakata City) found that total PAH content in unpolished rice ranged between 46 and 77 µg/kg. Out of ten groups of individual PAH molecules included in the study, the most abundant in rice and rice straw was found to be phenanthrene, which is also abundant in heavy fuel oil (Liu and Korenaga, 2001). Interestingly, a study from 2005 found that the spectra of individual PAH molecules (relative abundance of each molecule out of total PAH content) in all rice plant organs (including roots), more closely resembled those present in air than in soil (Tao *et al.* 2005).

As has been shown in the fisheries and mariculture sectors, the development of sampling protocols specifically for the resources at risk in a particular area, before an oil spill, could greatly reduce the uncertainty and disruption for those whose livelihoods depend on it. This local planning effort should extend to consideration of appropriate sampling methods for products cultivated in a given area or region. Past experiences should be key in informing the development of protocols for relevant agricultural products.

In the UK, following concerns regarding livestock during the response to BRAER, livestock sampling guidelines were improvised at the time, and then formalised. During the response to the SEA EMPRESS incident three years later, there were already effective sampling protocols in place to determine whether the food chain was at risk due to sheep ingesting oil contaminated vegetation, following the experiences of the BRAER incident. Monitoring led to the conclusion that although sheep tissue exhibited elevated concentrations of PAHs, these rapidly diminished over the next ten days to background concentrations (SEEC, 1998).

CONCLUSION

Recognition that agriculture-specific issues exist in certain areas vulnerable to marine oil spills can inform area planning and preparedness activities, which in turn may have implications at the operational and post-response phases, ultimately resulting in a reduction of social impacts and economic costs. Table 3 provides a summary of the key considerations in relation to coastal agriculture at each stage of an incident that have been found by the cases examined in this paper. In particular, where activities are regulated by cooperatives, there is greater organisational and functional capability to mitigate against the potential impacts of an oil spill. The involvement of cooperatives in all stages of the oil spill cycle, from planning to recovery is a key recommendation.

Table 3 Overview of agriculture resource-specific considerations highlighted by the case studies in this paper.

	Contingency planning considerations	Operational considerations
Cultivation cycle/seasonality	Risk assessment to factor time of year in the probability of a spill occurring and assess against the point in cultivation cycle of agricultural resources.	Response planning to incorporate cultivation cycle considerations into response prioritisation, and if necessary allocate resources for mitigation.
Coastal/hydraulic engineering	Accessibility to blueprints and maps for structures (e.g. *crues)* or hydraulic engineering (e.g. water channels) in information section of plan.	Close liaison and inclusion in response of individuals involved in normal maintenance of infrastructure.
Response caused damage	Identification of how preferred treatment options might impact infrastructure and address appropriate mitigation/ restoration prioritisation	Engagement of personnel involved in routine maintenance of infrastructure to undertake clean-up (if feasible) or restoration
Traditional/cooperative management	Identification of active cooperatives within area of contingency plan and inclusion of contact details in information section.	Dissemination of current and planned response related information to cooperatives which may provide assistance regarding agricultural issues.
Sampling	Development of resource specific sampling protocols.	Decision-making process must establish whether resources are considered to be at risk and require monitoring.

The common themes of the challenges encountered in the incidents examined here, involving different agricultural activities highlights that agriculture-specific considerations during the planning, response and post-spill phase are warranted, and that these should be informed by streamlined guidance to best practice approaches. This outcome will be achieved by documenting and incorporating lessons learned in previous incidents. To some extent, this happened in the UK following the livestock associated concerns raised by the BRAER and how they were treated during SEA EMPRESS.

It is recommended that following this initial overview, a more formal collation and assessment of the effects of oil spills on coastal agriculture around the world be produced. This would offer best practice guidance for governments, responders and those involved in coastal agriculture.

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