Impact of the *Deepwater Horizon* well blowout on the economics of US Gulf fisheries

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Abstract: Marine oil spills usually harm organisms at two interfaces: near the water surface and on shore. However, because of the depth of the April 2010 *Deepwater Horizon* well blowout, deeper parts of the Gulf of Mexico are likely impacted. We estimate the potential negative economic effects of this blowout and oil spill on commercial and recreational fishing, as well as mariculture (marine aquaculture) in the US Gulf area, by computing potential losses throughout the fish value chain. We find that the spill could, in the next 7 years, result in (midpoint) present value losses of total revenues, total profits, wages, and economic impact of US$3.7, US$1.9, US$1.2, and US$8.7 billion, respectively. Commercial and recreational fisheries would likely suffer the most losses, with a respective estimated US$1.6 and US$1.9 billion of total revenue losses, US$0.8 and US$1.1 billion in total profit losses, and US$4.9 and US$3.5 billion of total economic losses.

Résumé : Les déversements de pétrole en mer nuisent généralement aux organismes à deux interfaces, soit près de la surface de l'eau et sur la côte. Cependant, à cause de la profondeur à laquelle s'est produite l'éruption de *Deepwater Horizon* en avril 2010, les zones plus profondes du golfe sont vraisemblablement affectées. Nous estimons les effets économiques négatifs potentiels de cette éruption et du déversement de pétrole sur les pêches commerciales et sportives, ainsi que sur la mariculture (aquaculture marine) dans la région du golfe aux É.-U., en calculant les pertes potentielles dans l'ensemble de la chaîne de valeur des poissons. Nous trouvons que le déversement pourrait, dans les 7 prochaines années, entraîner des pertes en valeur actuelle (point milieu) de revenus totaux, de profits totaux et de salaires et un impact économique de respectivement 3,7, 1,9, 1,2 et 8,7 milliards de $US. Les pêches commerciales et sportives subiraient vraisemblablement les pertes les plus élevées, avec des pertes totales de revenu respectives de 1,6 et 1,9 milliards $US, des pertes de profit total de 0,8 et de 1,1 milliards $US et un impact économique total de 4,9 et de 3,5 milliards $US.

[Traduit par la Rédaction]

Introduction

On 20 April 2010, the *Deepwater Horizon* (DH), an oil rig leased by British Petroleum (BP), exploded in the Gulf of Mexico (GOM) and began leaking oil from the seabed at a depth of over 1500 m. On Monday, 1 August 2010, the US government stated that BP's ruptured well had gushed an estimated 4.9 million barrels of oil (780 million L), making it the largest accidental marine oil spill in US waters (Levy and Gopalakrishnan 2010; Urriza and Duran 2010). In contrast, the 1989 *Exxon Valdez* oil spill, a major disaster in US history, amounted to less than 0.5 million barrels (80 million L). Given the likely economic and legal repercussions of this major pollution event, a rapid first-order estimation of the likely economic losses due to the oil leaks is required. Here, we present such a preliminary estimate using a top-down approach to set a baseline for future, hopefully more detailed, comprehensive economic assessments.

Besides obvious environmental effects, oil spills can have extensive socio-economic, psychological, and even cultural impacts, including effects on marine resource use and livelihoods (e.g., fisheries) and public health (Anonymous 1989; 1990*a*; Palinkas et al. 1993). Impacts on marine ecosystems can persist for extended periods and stem directly from the destruction of habitats, death and pollution of plants and animals, and changes to food web structure and function. For example, the environmental and economic effects of the 1989 *Exxon Valdez* spill in Prince William Sound, Alaska,

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were still being felt in the early 2000s (Graham 2003). The impacts on marine ecosystems translate into impacts on the economy and livelihoods, including commercial fisheries, recreation, mariculture (marine aquaculture), tourism, and energy markets. Fish caught from contaminated areas or neighboring locations will raise concerns about food safety. These effects call for actions to mitigate, recover, and prevent the incidence of oil spills, which are costly to society.

The coast of the GOM is made up largely of saltwater marshes, mangroves, wetlands, and estuaries, which are important nursery and foraging areas for many marine species. Within these ecosystems, there are over 15 000 species of fauna and flora (Felder and Camp 2009), including whales, turtles, manatees, sharks and other fishes, shrimps, crabs, mollusks, birds, seagrasses, and mangroves. Many of these species are highly valued by commercial and recreational fisheries, including brown shrimp (*Farfantepenaeus aztecus*), blue crab (*Callinectes sapidus*), eastern oyster (*Crassostrea virginica*), red snapper (*Lutjanus campechanus*), Gulf menhaden (*Brevoortia patronus*), and bluefin tuna (*Thunnus thynnus*). Additionally, one of only two existing Atlantic bluefin tuna spawning grounds is located in the GOM. Large-scale pollution events, such as the DH spill, can result in impacts that are both direct (e.g., acute-phase mortality) and indirect (e.g., bioaccumulation through the food web). Indirect effects have been shown to persist for decades (Graham 2003).

Long-term studies on salt marsh habitat following the *Florida* barge spill in Wild Harbor, Massachusetts, USA, in 1969 demonstrate the persistence and impacts of oil within sediments (Culbertson et al. 2007, 2008*a*, 2008*b*). Buried hydrocarbons result in the destruction of seagrass root structure and subsequent losses of grass cover and increased erosion even 40 years later (Culbertson et al. 2008*a*).

Within tropical ecosystems, mangroves are considered to be among the most susceptible to impacts from oil spills (Shigenaka 2002). Studies of mangrove habitats after the 1986 spill of 50 000 barrels from the *Galeta* near the Panama Canal demonstrate the influence of sediments acting as long-term reservoirs of oil (Burns et al. 1993). The persistence of the oil was unexpected because of relatively warm tropical waters, which were thought to increase the rate of breakdown of the hydrocarbons. Short-term effects included dead mangroves along 27 km of coastline even 1½ years after the spill (Jackson et al. 1989) and the deterioration of surviving mangroves up to 6 years after the spill (Burns et al. 1993). Long-term effects were not only apparent in the mangroves themselves, but also detected in the species found associated with the root structure (i.e., bivalves).

Coral reefs are one of the most diverse marine ecosystems and host highly complex communities (Haapkyla et al. 2007). Besides obvious lethal effects of oil, sublethal effects such as reduced reproductive efficiency have also been demonstrated (Loya and Rinkevich 1980). Haapkyla et al. (2007) reviewed the impacts of oil and oil spills on corals and found that corals were negatively impacted, leading to decreases in coral cover, growth, reproductive output, and species diversity. Only in two cases were no or only minor effects found, these being the Arabian Gulf field experiment in 1989 (LeGore et al. 1989) and oil spills in the Arabian Gulf related to the Gulf War in 1991 (Downing and Roberts 1993; Price 1998).

Unlike the visually obvious and immediate effects on birds and mammals, the effects of oil on fisheries can be more difficult to detect, though they are no less devastating. Oil spreads through the marine ecosystem and damages coastal areas important as nurseries for juvenile fish and shrimp. Oil and hydrocarbons are taken up by plankton and other surface-dwelling species that link to aquatic food chains. Thus, oil moves through the food web and accumulates in food fishes, posing serious health concerns for consumers. Almost immediately following the DH spill, the region's key shrimp and oyster fishing areas were officially closed. According to the US National Marine Fisheries Service, 70% of the commercially caught shrimp and oysters in the US come from the GOM (National Oceanographic and Atmospheric Administration 2010).

Several studies have examined the effects of oil on fish and invertebrate species. The *Exxon Valdez* oil spill in Alaska in 1989 had notable effects on important fish species, such as Pacific herring (*Clupea pallasii*) and pink salmon (*Oncorhynchus gorbuscha*), including premature hatching, reduced growth rates, morphological and genetic abnormalities, and increased mortality (Bue et al. 1998; Rice et al. 2001). Adult Pacific herring showed evidence of liver lesions and increased disease due to depressed immune function (Moles et al. 1993; Carls et al. 2001). These effects contributed to increased natural mortality in adult Pacific herring over a 5-year period (Thorne and Thomas 2007). Research on biomarkers of hydrocarbon exposure in nine species of pelagic and demersal fish showed that 10 years after the *Exxon Valdez* spill, signs of exposure were still present (Jewett et al. 2002). Consequences have been shown to be more severe for invertebrates because of their sessile nature and close association with contaminated habitats, including declines in abundance, growth rate, and condition (Culbertson et al. 2007, 2008*a*). Sediments and intertidal mussel beds (*Mytilus trossulus*) showed evidence of contamination 6 years after the *Exxon Valdez* oil spill and were a source of chronic contamination for predatory species (Carls et al. 2001).

In addition to direct effects on individual species, food web interactions allow for the propagation of negative impacts to higher trophic levels. The impact of the *Tsesis* oil spill on benthic organisms in the Baltic Sea in 1977 resulted in food chain transfer of oil to flounder (*Platichthys flesus*; Elmgren et al. 1983).

The magnitude and duration of impacts will depend on the scale of the spill, the type of hydrocarbon, and the characteristics of the marine environment. Benthic and relatively sessile organisms (e.g., crabs, clams, mussels, and shrimps) suffer high initial mortalities, displacement, or contamination (becoming unmarketable) of up to 100% (Teal and Howarth 1984). Mobile fish species are generally subject to lower initial mortality rates, although those can quickly rise in large spills. For example, the 1979 *Ixtoc I* blowout, previously the largest accidental oil spill in history, is estimated to have caused 50%–70% fish mortality in adjacent coastal regions (Jernelov and Linden 1981).

There are many studies that examine the initial impacts of oil spills on species, yet few consider the time scale for marine organisms to recover from exposure. Recovery time is dependent on the length of exposure, water temperature, oceanographic features of the region, mobility, and ontogenetic stage of the species, as well as species-specific life history traits (e.g., feeding and reproductive patterns). The ability of critical habitats to act as long-term reservoirs of oil can extend exposure and subsequent recovery times. While habitat recolonization can begin within 3 to 6 months, it generally takes at least 1 year for pollutant concentrations in marine organisms to return to prespill conditions (Teal and Howarth 1984). This assumes that the spill has ended and most oil cleaned up, so the minimum duration of impacts can be well over 1 year. In fact, oil concentrations in sediment, where it is most persistent, have been detected up to 40 years after a spill (Culbertson et al. 2008*a*). All of these effects depend to a great extent on the type of ecosystem affected. In tropical systems like the GOM, impacts can be exacerbated by a high proportion of mangroves and marshes, which capture and retain oil for prolonged periods, affecting organisms that depend on these habitats for food, reproduction, and shelter (Jackson et al. 1989).

There are numerous economic assessments of oil spills, which can be adapted for the current assessment. Cohen (1995) estimated the social costs (i.e., cost to society as opposed to private cost to a firm or an individual) of the 1989 *Exxon Valdez* spill for the years 1990 and 1991 by examining the revenue difference between actual fisheries catches with and without the spill. García-Negro et al. (2009) studied the economic impact of the 2002 *Prestige* oil spill on the affected coastline in Spain, investigating the fisheries landings before and after the accident. The McDowe Group used business surveys to determine the economic effect of the *Exxon Valdez* spill on Alaska's tourism industry (Anonymous 1990*b*). A study by Advanced Resources International provided estimates of economic impacts for many oil spill accidents by dividing spills into three types: tanker, pipeline, and offshore platform, and determined the cost for clean-up, oil losses, environmental and resource damage per gallon (1 gallon = 3.785 L) of oil spilled to be US$260, US$1.71 and US$9.91–19.81, respectively (Anonymous 1993). Clean-up costs and environmental damage from tanker spills are highly variable, but can be particularly high if the spill occurs in remote and environmentally sensitive areas, as has occurred in the past. Offshore facilities have a relatively good safety record, so spill effects are more poorly defined. However, large blowouts close to sensitive coastal areas such as marshland or reefs can lead to substantial ecological and economic damages (e.g., *Ixtoc I*, 1979; *Union Platform A*, 1969); the DH blowout is unfortunately one such case.

An important consideration in this study is the potential market recovery times (i.e., the time required for market conditions for the affected fish species to return to prespill levels) of commercially important species in the GOM. There is a distinct difference between ecological and market recovery times. As mentioned above, ecological recovery can take decades, especially for organisms associated with sediments such as crustaceans and mollusks. Market recovery time, on the other hand, depends on the length of fisheries closures after a spill, public perceptions of seafood safety, and the degree of tainting (both visible and with respect to taste and smell of seafood; Moller et al. 1999).

The oil industry typically touts the quick recovery of organisms to an "untainted state" as evidence of the safety of seafood after an oil spill (e.g., Moller et al. 1999). However, after the *Exxon Valdez* spill, fisheries for salmon, herring, crab, shrimp, rockfish, and sablefish were closed, with some commercial fisheries remaining closed through 1990. Herring and salmon species in the region have never fully recovered ecologically or economically. One of the main reasons for this is the public perception of contamination from seafood (see http://useconomy.about.com/od/suppl1/p/Exxon_Valdez_Oil_Spill_Economic_Impact.htm).

Materials and methods

The GOM ecosystem supports considerable commercial and recreational fisheries, as well as mariculture, all of which are affected by spilled oil. To provide a broad picture of the economic effects of the spill on these three sectors, we estimate the potential losses in (*i*) total revenues; (*ii*) total profit (payment to capital plus resource rent); (*iii*) wages (payments to labor); (*iv*) number of jobs; and (*v*) economic impact throughout the wider economy. To provide conservative estimates of the economic effects of the oil spill, we use estimates of market recovery time rather than longer ecological recovery time horizons.

Total revenue is the product of ex-vessel price and catch in the case of commercial fisheries; the total expenditure in the case of recreational fisheries; and the product of ex-farm price and production quantity in the case of mariculture. Total profit is the sum of normal profit and resource rent. Normal profit (payment to capital) is the opportunity cost of the capital invested to run fisheries or mariculture. Resource rent is payment to the "owners" of marine resources (i.e., the American people in the case of commercial and recreational fisheries). Wages (payments to labor) are the amounts earned by people who expend their labor, skills, and expertise in the sector. The added value or impact through the fish value chain is the indirect economic effects of fisheries and mariculture because of their impact on activities such as boat building or maintenance, equipment supply, and the restaurant sector (Pontecorvo et al. 1980).

We assume that each economic indicator is related to landings (L) in the following manner:

(1) $\text{total revenue} = L \cdot p$

(2) $\text{normal profit} = L \cdot \pi$

(3) $\text{wages} = L \cdot w$

(4) $\text{rent} = L \cdot p - L \cdot c$

(5) $\text{impact} = L \cdot p \cdot M$

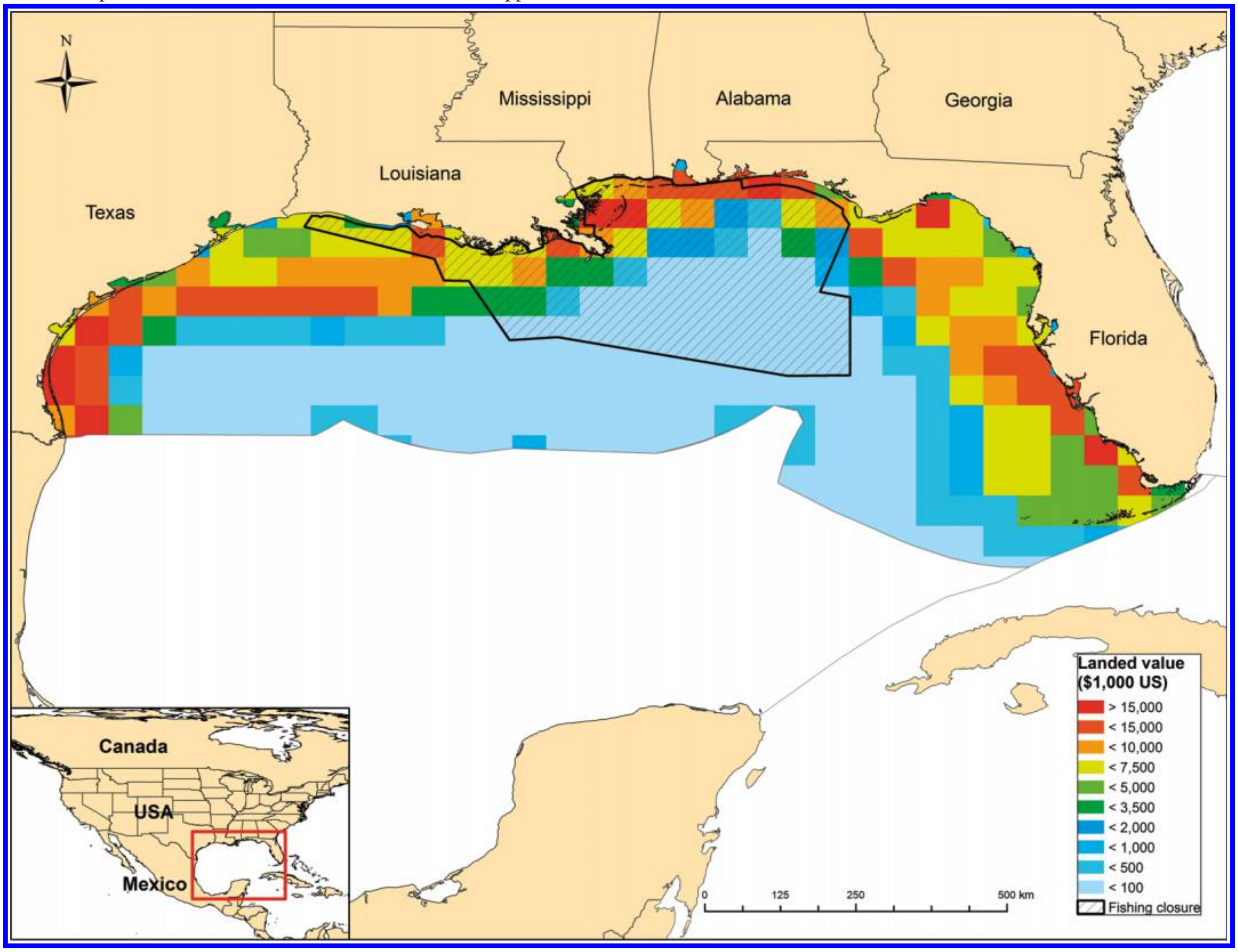
where p, π, w, and c represent price, profit, wages, and costs, respectively, per tonne. The parameter M represents the economic impact multiplier for fisheries of the US as estimated by Dyck and Sumaila (2010).

The present value of each indicator i over time t is expressed as

(6) $$\text{PV}_i = \sum_{t=0}^{T} \delta_i^t X_{i,t}$$

where $X_{i,t}$ represents economic indicator i at time $t = 0 \ldots T$,

Fig. 1. Spatial distribution of the annual average landed value of the total commercial fisheries catch in the US Exclusive Economic Zone in the Gulf of Mexico (averaged for the 2000–2005 period). The area closed to commercial fishing (as of 22 July 2010) includes both federal waters and portions of western Florida, Alabama, Mississippi, and Louisiana state waters.



and the parameter δ is the discount factor determined using the appropriate rate of discount applicable to the US. The discount factor is calculated using a real discount rate of 3.0%.

Modeling oil spill impacts

We use the Sea Around Us Project (http://www.seaaroundus.org) global grid-map system of half degree latitude by half degree longitude cells of spatially assigned annual commercial catch (Watson et al. 2004) and landed values of catch (http://feru.org; Sumaila et al. 2007) taken by US fisheries in the US Gulf Exclusive Economic Zone (EEZ). We then overlay on this landed value map the area of the GOM that was closed to fishing at its largest extent (as of 22 July 2010), including federal and state waters (Fig. 1). Using this combination of spatial data, we calculate the likely proportion of landed value that is immediately unavailable to the fishing sector. This approach has also been applied in McCrea-Strub et al. (2011).

As foreign fishing vessels have been prohibited from operating within the US EEZ since 1991, fisheries closures are also assumed only to impact US fisheries. However, the GOM is a dynamic system, and oil and dispersants have not been confined to the sea surface, with subsurface plumes (50–1200 m) having been documented (Camilli et al. 2010). Most marine organisms, including those mentioned here, exhibit daily and seasonal, small- and large-scale migrations both laterally and vertically. Marine organisms may be directly impacted by physical contact with contaminants as well as indirectly affected via the fouling of important nursery and spawning habitats as well as food chain interactions. Therefore, it is unlikely that the effects of the spill will be spatially and temporally restricted to closed area boundaries and closure duration.

Estimates of loss in commercial, recreational, and mariculture fisheries are dependent on the combination of initial mortality of fish species due to the oil spill as well as the continued economic unmarketability that can result when consumers believe marine products from the GOM are less desirable because of real or perceived pollutants. In the case of the *Exxon Valdez* spill, full market recovery of the tourism and sport fishing sector in Alaska is reported to have occurred within 2 years after cleanup (Anonymous 1993); in the case of the *Amoco Cadiz* spill in Brittany, tourism activities returned to prespill levels 1 year after cleanup (Grigalu-

Table 1. Assumed impact gradient (%) for species group – state combinations in the area open to fishing (Area B) in the Gulf of Mexico.

Group	Florida (west)	Alabama	Mississippi	Louisiana	Texas
Mollusks	30	45	50	50	0
Crustaceans	30	45	50	50	0
Benthic fishes	15	23	25	25	0
Pelagic fishes	6	9	10	10	0

Table 2. Estimated annual catch and catch values before the Gulf of Mexico oil spill in the areas closed and open to fishing as of 22 July 2010.

	Closed area (A)		Open area (B)	
Group	Catch (t)	Value (million US$)	Catch (t)	Value (million US$)
Mollusks	13 357	13.4	52 219	53.3
Crustaceans	21 938	99.3	73 608	334.2
Benthic fish	2 648	7.8	10 825	30.7
Pelagic fish	79 869	22.8	331 405	94.7
Total	117 813	143.3	468 058	513.0

Table 3. Assumed initial unmarketability and market recovery time for key marine taxonomic groups targeted by commercial fisheries in the Gulf of Mexico.

Group	Includes	Initial unmarketability (%)	Market recovery time (years)
Mollusks	Clams, mussels, oysters	100	1–6[a,b]
Crustaceans	Shrimp, crabs, lobsters	100	1–7[b,c]
Benthic fish	Soles, flounders, rockfish	50	1–2[b,d,e,f]
Pelagic fish	Tunas, sharks, jacks, mullets	10–30	0.16–1[b,g,h]

Note: Initial mortality also includes displacement or contamination to unmarketable levels. Recovery time refers to a return to prespill biomass and begins once all visible oil has been cleaned or dissipated.

[a]Jackson et al. 1989.
[b]Teal and Howarth 1984.
[c]Teal et al. 1992.
[d]Jernelov and Linden 1981.
[e]Elmgren et al. 1983.
[f]Lee and Page 1997.
[g]Grigalunas et al. 1986.
[h]Cedre 2008.

nas et al. 1986). The market "recovery" times used for recreational fisheries are shorter than for commercial fisheries because of the inherent differences between recreational and commercial fishing, with the latter catching fish for consumption, while recreational fishers are not motivated by this factor alone and are likely to return to fishing sooner (Arlinghaus 2006; Fedler and Ditton 1986). Finally, we assume impact gradients in the currently closed area for the second and third years to be 50% and 25%, respectively, because we expect the impact of the spill to fade away with time (Table 1).

Commercial fishing

Using the spatial catch and value data displayed (Fig. 1), we estimate the average annual catch and landed values taken before the oil spill (2000–2005) within areas closed to fishing (Area A) and open to fishing (Area B; Table 2) by major species groups (see below for details on species groups). We assume that the economic indicators are affected differently in open versus closed areas as described below.

We use the equation below to estimate the loss in landings arising from areas closed (C^{closed}) and open (C^{open}) to fishing:

$$\text{(7)} \qquad \text{loss}_{g,s} = \left(C_{g,s}^{\text{closed}} + \mathbf{M}_{g,s} \cdot A_{g,s} \cdot C_{g,s}^{\text{open}} \right)$$

where the indices g and s refer to species groups and states, respectively. The matrix $\mathbf{M}$ represents the initial mortality of marine species groups due to the oil spill, and A denotes the proportion of landings for a given species group – state combination affected by the oil. For simplicity, the loss is assumed to be experienced throughout the length of the market recovery time, $t \in [1, T]$, for a given species group. A range of estimated recovery times (Table 3) are used to compute a range of estimates of the present value of each economic indicator calculated by substituting the loss in landings, $\text{loss}_{g,s}$,

Table 4. Preoil spill mariculture production in the Gulf of Mexico.

State	Product	Production (t)	Production value (million US$)	Employment (jobs)
Alabama	Shrimps	100	0.7	10
Florida	Clams	7 030	10.3	210
Louisiana	Oysters	51 400	41.5	250
Total		58 530	52.5	470

Note: Production values adjusted to 2010 US$.

into eqs. 1–5, summing across species groups and states, and using eq. 6 to compute the present value of economic effects.

Employment data for commercial fisheries in the Gulf are from National Marine Fisheries Service (2010). We collect direct, indirect, and induced employment data by state. By considering indirect and induced employment, we include jobs that are supported by marine fisheries throughout the region's economy. We estimate potential employment loss by assuming that a reduction in the value of marine landings will be followed by a proportional change in the number of workers employed.

Recreational fisheries

To estimate the economic indicators for recreational fisheries, we rely on surveys undertaken by the US Fish and Wildlife Service (Anonymous 2006*b*), which reports the number of recreational fishers (resident and nonresident) by state, as well as the expenditures by anglers. Under the assumption that the percentage of resident anglers has remained constant since 2006, we calculate the total number of resident anglers based on 2009 population projections (http://www.census.gov). We use the ratio of resident to nonresident anglers to estimate the total number of anglers per state and the total number of fishing trips. With regard to Florida's west coast, we use the proportion of recreational fishing that takes place along the west coast (Steinback et al. 2004).

To estimate the total expenditure (or total revenues generated by the sector) and the economic impact, we use reported expenditures (Steinback et al. 2004) converted to 2010 dollars based on the US consumer price index (http://www.bls.gov/CPI). These expenditures include payments for fishing-related items (gear, tackle, etc.) and travel costs to the fishing locations, including private, guided, and charter fishing trips. We exclude expenditure on durable items (i.e., second homes), assuming that these will not be substantially affected. We make the strong assumption that recreational fishing will continue in the area open to fishing (Area B) at the prespill level. For the closed area (Area A), first year economic effects of the spill are based on the spatial extent of the fishing closures (Fig. 1). The resource rent and profit share of total revenue is estimated by summarizing the literature on the topic (Carter 2003; Marshall and Lucy 1981; Galeano et al. 2004).

Losses due to the oil spill are then calculated using the following equation:

$$(8)\qquad \mathrm{loss}_{s,t} = \left(1 - P_t^{\mathrm{closed}}\right)X_s$$

where $\mathrm{loss}_{s,t}$ is the change in an economic indicator, X_s, for state s at time t. The parameter P_t^{closed} represents the percentage of waters in the GOM closed to fishing at time t. At the time of writing, 24% of American waters in the GOM are closed to recreational fishing. We assume that the percentage of waters unavailable to recreational fisheries will decrease to zero after 3 years, with their share in the second and third years being 12% and 6%, respectively. Present values of loss for each of the economic indicators (except for employment) are estimated using eq. 6.

The economic impact of changes in total revenue due to the oil spill is estimated using eq. 9 (see Appendix A for more on impact multipliers):

$$(9)\qquad \mathrm{impact} = \sum_s \mathrm{PV}_s \cdot M_s$$

where PV_s is the present value of total revenue in a given state s, and M_s is the state-specific economic multiplier as reported by Steinback et al. (2004). Employment is calculated based on information from Steinback et al. (2004), and it is assumed to change in proportion to changes in losses associated with the oil spill.

Mariculture

Mariculture in the GOM is focused on invertebrate species, particularly oysters. According to the 2005 US Census of Aquaculture (Anonymous 2006*a*), Louisiana accounts for the largest share in mariculture production (51 400 tonnes of oysters worth US$37 million in 2005) in the US, with further contributions from Florida (7000 tonnes of clams worth US$9 million) and Alabama (100 tonnes of shrimp worth US$630 000; Table 4). No mariculture has been reported for Texas.

Owing to the fact that mariculture in Florida, Louisiana, and Alabama is primarily for crustaceans and mollusks, we assume that the impacts of the spill on mariculture will be similar to those on commercial fisheries for crustaceans and molluscs, namely that the contamination will result in zero market recovery.

Based on the location of the current closure, we assume that 100% of mariculture operations in Louisiana and Alabama and 10% of operations in west Florida are affected. Moreover, since oyster mariculture occurs in 2-year cycles from seeding to harvesting, we assume that the exposure to the spill will result in 3 years of lost oyster harvest (2010, 2011, and 2012). However, assuming that sufficient oyster larvae can be recruited from uncontaminated broodstocks in 2011, we expect the industry to recover in early 2013. Here, we focus solely on the impact due to loss of harvest and ignore the potential long-term losses from a decrease in demand due to consumer fears over residual contamination risks.

Table 5. Predicted present value losses in economic indicators for commercial fisheries over the next 7 years in the US Gulf of Mexico area due to the *Deepwater Horizon* oil spill.

Group	Revenues (million US$)	Total profits[a] (million US$)	Wages (million US$)	Economic impact (million US$)	Employment (jobs)
Crustaceans	360–2307	155–987	79–507	1114–7151	—
Mollusks	53–297	67–369	53–297	165–920	—
Benthic Fish	22–43	18–35	2–4	68–133	—
Pelagic fish	35–58	26–43	8–14	106–176	—
Total	470–2705	266–1434	142–822	1453–8380	5250–8758[b]

[a]This is the sum of normal profits (payment to capital) and resource rent (payment to resource owners).

[b]Employment data are available only by state, not species. This number represents total employment loss for all of the US Gulf states. To produce a range, we calculate 7000 (±25%).

Table 6. Predicted present value loss in economic indicators for US Gulf states' recreational fisheries.

State	Total revenues (million US$)	Total profits (million US$)	Wages (million US$)	Economic impact (million US$)	Employment (jobs)
Florida	994–1 656	542–903	378–630	1 772–2 953	7 650–12 750
Alabama	111–185	60–100	38–64	195–325	900–1 500
Mississippi	59–98	32–53	17–28	119–198	375–625
Louisiana	278–464	152–253	95–159	473–788	2 025–3 375
All states	1 442–2 404	786–1 310	528–881	2 558–4 264	10 950–18 250

From our estimates of lost revenue, we compute the profit and wages lost. The cost structure of mariculture operations in the GOM region was not available to us; we therefore use information from oyster farming in Virginia (Lipton et al. 2006) to estimate the potential loss in profit (~47%) and wages (~20%) from total revenue. Because of the nature of mariculture (i.e., requiring input by operators to generate harvest), we assume that all of the profit is return to capital with no resource rent. As in commercial fisheries, the present value of the lost revenue, profit, and wages are calculated using eq. 1.

We assume the current level of output from mariculture to be similar to that reported in the 2005 US Census of Aquaculture (Anonymous 2006*a*), converted to 2010 US$ equivalent (Table 4). The employment figures are estimated from the state total using the ratio of mariculture farms to total number of aquaculture farms in each state (Anonymous 2006*a*).

The economic impact of losses in total mariculture revenue is estimated by adapting eq. 5 to mariculture production, changing it to

$$\text{impact} = \text{PV}_{\text{revenue}} \cdot M \tag{10}$$

where $\text{PV}_{\text{revenue}}$ is the present value of loss due to the oil spill, and M is the economic input–output multiplier from Dyck and Sumaila (2010).

Results

Commercial fisheries

The present value of total revenues that would be lost in the commercial fishing sector over the next 7 years, due to the DH well blowout, is estimated to be in the range of US$0.5–2.7 billion (Table 5). The equivalent losses in total profits, wages, and total economic impact are estimated at US$0.3–1.4, US$0.1–0.8, and US$1.5–8.4 billion, respectively. By far the largest losses are incurred among fishers targeting crustaceans such as shrimps, who would experience nearly 85% of the total estimated economic impact (Table 5). In addition, between 5000 and 9000 jobs may be lost by commercial fisheries in the US Gulf region (Table 5).

Recreational fisheries

The present value of losses in the recreational fishing sector are estimated to be US$1.4–2.4 billion in total revenues, US$0.7–1.3 billion in total profits, US$0.5–0.8 billion in wages, and US$2.5–4.2 billion in economic impact (Table 6). The recreational fishing sectors in Florida and Louisiana are predicted to suffer the largest impacts, with Florida accounting for most of the expected losses (Table 6). Between 11 000 and 18 000 jobs may also be lost in this sector (Table 6). Note that no losses have been predicted for Texas.

Mariculture

For the three mariculture states, Florida, Alabama, and Louisiana, the total loss in revenue is estimated to be US$94–157 million, with an economic impact of about US$293–488 million (Table 7). We estimate a loss of US$44–73 million in total profit and US$19–31 million in wages. The sector may lose well over 210 jobs, both full- and part-time (Table 7). Overall, the majority of economic losses will occur in oyster mariculture (Table 7).

Overall, the present value of (midpoint) losses in total revenues, total profits, wages, and economic impact from the three sectors considered here are about US$3.7, US$1.9, US$1.2, and US$8.7 billion over the next 7 years, respectively (Table 8). The likely largest losses can be expected from the commercial fisheries, while the recreational fishing sector may account for slightly more than a third of such

Table 7. Predicted present value losses in economic indicators for US Gulf mariculture.

Group	Revenues (million US$)	Normal profits (million US$)	Wages (million US$)	Economic impact (million US$)	Employment[a] (jobs)
Crustaceans	1.5–2.5	0.7–1.2	0.3–0.5	4.7–7.8	8–13
Mollusks	92–154	43–72	18.5–30	287.8–479.8	203–338
All species	94–157	44–73	19–31	293–488	211–351

[a]25% error ranges on the median assumed.

Table 8. Predicted (midpoint) present value losses in economic indicators for all affected US Gulf states for commercial and recreational fisheries and mariculture sectors combined.

Sector	Total revenues (million US$)	Total profits (million US$)	Wages (million US$)	Economic impact (million US$)	Employment (jobs)
Commercial fisheries	1 577	823	469	4 888	7 000
Recreational fisheries	1 949	1 062	715	3 457	14 900
Mariculture	129	61	26	399	280
Total	3 655	1 946	1 210	8 744	22 180

losses. Furthermore, the region may lose over 22 000 jobs in fisheries-related sectors (Table 8).

Discussion

We focus exclusively on the potential economic impacts of the DH well blowout on commercial and recreational fisheries, as well as mariculture in US Gulf waters, and find that the impacts are quite significant. The blowout could, over the next 7 years, result in (midpoint) lost revenue, profit, wages, and total economic impact with a present value of US$3.7, US$1.9, US$1.2, and US$8.7 billion, respectively. We also find that over 22 000 jobs in the GOM economy may be lost. Therefore, our analysis suggests that the spill will result in considerable loss of income to households and businesses in the Gulf states because of losses in wages and profits, respectively. Our estimates include downstream and upstream indirect and induced economic impact to industries such as boat building, the restaurant sector, and fuel suppliers.

However, there are other potential economic impacts not covered here (see e.g., Boyd 2010), including (*i*) clean-up cost; (*ii*) value of lost oil; (*iii*) natural and environmental damage beyond fisheries impacts; (*iv*) other direct use impacts such as bird watching and other non-fish tourism (Oxford Economics (2010) suggests a potential loss in US tourism revenues at over US$22 billion); and (*iv*) non-use existence and option values. Additionally, 11 people died in the explosion and 17 were injured. These are unrecoverable losses to affected families and the US at large.

Even for the sectors we study, our estimates are not complete. For instance, we do not consider consumer impacts through increases in fish prices due to reduced supply caused by the spill. Also, we focus on the short-term (up to 7 years) impacts and losses, thereby ignoring long-term effects. Some unintended consequences of the spill may also exist (e.g., the potential benefits of a forced fishing moratorium may help rebuild some stocks in the medium to long term). Furthermore, a potential spill injury to the Gulf fisheries can arise in response not to actual contamination by oil but over public perception of potentially contaminated fish that can lead to closures so that demand remains high for other fishes or the same fishes from other areas, thereby affecting the economics of Gulf states fisheries. For instance, US demand for shrimp from Thailand increased right after the oil spill. Having said the above, it is worth noting that one consequence of the reduction in shrimping effort due to the oil spill is reduction in bycatch of groundfish species, which is a positive for fisheries targeting these species, and could mitigate the losses calculated in this contribution.

It is important for the reader to note that we used a number of models, each with underlying assumptions, which may affect the accuracy of our results, and this is the reason why our estimates have ranges. For example, the input–output analysis applied in this paper is not without criticism (e.g., Christ 1955; de Mesnard 2002); it is well known that input–output analyses rely on the stability of technical coefficients, which may not hold when used in forecasting situations that are greatly different than those described by the respective input–output table used. Furthermore, input–output analysis is fairly data intensive — a factor that can be problematic when studying regions with scattered high-quality data sources. These caveats notwithstanding, we believe that our findings, which are different from those presented by the Feinberg Commission, are likely more accurate because of the passage of time and the thoroughness of the review process.

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Appendix A. More on input–output models

As a primary industry (i.e., activities focusing on extracting or processing natural resources, such as energy, minerals, and in this case food, for use elsewhere in the economy), fishing is the beginning of a productive value chain in an economy. The economic multiplier is used in fisheries research to emphasize that the industry has many linkages throughout the economy. Such multipliers are a factor by which we can multiply the value of final demand for an economic activity's output to obtain its total contribution to economic output, including activities directly and indirectly dependent on it.

More specifically, the multipliers used in this study are taken from Dyck and Sumaila (2010). The model configurations, presented in this reference, are briefly described below.

The method developed by Nobel laureate, Wassily Leontief, known as input–output analysis, is a tried and tested approach to analyzing the structure of the economy. Beginning as early as the late 1940s, Leontief used his method in a number of applications, including the well-known analyses of the potential economic impact of disarmament for the United States of America and tests of the Heckscher–Ohlin theory now known as the "Leontief Paradox" (Leontief 1953; Leontief et al. 1965). The definitive source on input–output methodology, his book on the subject is a collection of his earlier works and serves as an excellent foundation for using input–output analysis (Leontief 1966). There are, however, several additional sources for readers who are interested in the methodology as applied to fisheries (Heen 1989; Hoagland et al. 2005; Jin et al. 2003; Leung and Pooley 2001; Roy et al. 2009).

Input–output analysis uses interindustry transaction data to compute a technical coefficient matrix, **A**, which is composed of entries $a_{i,j}$ summarizing the output from industry i required to produce a unit of output for industry j. We compute this technical coefficient matrix for every maritime country of the world, expressing the economy of each country as a system of linear equations summarized by the following equation:

$$\text{(A.1)} \qquad \mathbf{A}\boldsymbol{x} + \boldsymbol{d} = \boldsymbol{x}$$

where **A** is the matrix of technical coefficients describing input requirements for each sector, $\boldsymbol{x}$ is a vector of sector inputs, and $\boldsymbol{d}$ is a vector of final demand. The above equation then simply states that the sum of intermediate demand ($\mathbf{A}\boldsymbol{x}$) and final demand ($\boldsymbol{d}$) is equal to supply ($\boldsymbol{x}$). It is then a simple problem of linear algebra to solve for the vector of inputs ($\boldsymbol{x}$) required to satisfy a given final demand vector ($\boldsymbol{d}$) using **I** as the identity matrix. This solution is expressed as

$$\text{(A.2)} \qquad \boldsymbol{x} = [\mathbf{I} - \mathbf{A}]^{-1}\boldsymbol{d}$$

We note that the vector $\boldsymbol{x}$ represents total output supported by the demand vector $\boldsymbol{d}$. It is important to keep this measure of economic activity separate from other measures such as value-added, which subtracts the value of inputs from the value of output. It is worth noting that it is not appropriate to make comparisons between estimates using input–output analysis and measures of value-added such as gross domestic product (GDP).

Type I & II output multipliers

Given the solution in eq. A.2 above, we calculate the change in output with respect to final demand. To do this, we take a partial derivative of eq. A.2 with respect to final demand ($\boldsymbol{d}$):

$$\text{(A.3)} \qquad \frac{\delta \boldsymbol{x}}{\delta \boldsymbol{d}} = [\mathbf{I} - \mathbf{A}]^{-1}$$

Equation A.3 describes a new relationship that proves to be very useful in macro-economic analysis. The right-hand side of this equation, $[\mathbf{I} - \mathbf{A}]^{-1}$, is also denoted as $\mathbf{L}^{-1}$, as it is commonly called the Leontief inverse or multiplier matrix. This square matrix is of such interest because each entry (denoted $\mathbf{l}_{i,j}$) describes the marginal inputs required from sector i when the output of sector j increases by one unit.

We calculate industry multipliers by computing the column sum of the Leontief inverse matrix $\mathbf{L}^{-1}$ as $\boldsymbol{M} = \sum_{j=1}^{N} \mathbf{L}_{i,j}$ where $\boldsymbol{M}$ is a row vector of Type I industry output multipliers. Each entry, $\boldsymbol{M}_j$, in this row vector is an output multiplier that allows us to compute the direct and indirect output required to support a unit of output for industry j. For example, in a sector with a multiplier of 1.5, we would estimate that US\$100 in final demand from this sector supports US \$150 of activity throughout the economy.

As we have shown, for a given economy with n industries, one calculates the Leontief inverse using a $n \times n$ technical coefficients matrix as described above. Multipliers calculated in this way account for the direct and indirect output supported by a given industry. In addition to these multipliers, often called Type I, a second set of multipliers, called Type II, may also be calculated. The advantage to using Type II multipliers is that they account for indirect as well as induced effects that occur, for example, when additional demand for a given sector increases household incomes that induce demand for additional output. With Type I multipliers, household consumption is part of the final demand sector and therefore assumed to be exogenous; with Type II multipliers, we treat household consumption as endogenous by adding it as an additional intermediate sector in the technical coefficients matrix **A**. When computing Type II output multipliers, a technical coefficients matrix with endogenous households will be $(n + 1) \times (n + 1)$ in dimension. Summing the multiplier matrix $\mathbf{L}^{-1}$ over n output sectors will produce Type II output multipliers that include the induced effect of endogenizing households without confusing output and income, which would occur if we added the last row of the multiplier matrix — also known as the income effect.

Researchers have adopted approaches to account for direct and indirect effects of fisheries in literature. A considerable amount of this previous work using economic impact methodology has been done for the USA (e.g., Seung and Waters 2006). Several methods used in such studies to analyze the economic impacts of fishing including input–output modeling, social accounting matrix (SAM) modeling, econometric input–output (EC-IO) modeling, fisheries economic assessment models (FEAM), and computable general equilibrium (CGE) models. Each of these techniques has its merits and demerits, which have been discussed in the literature at length (Loveridge 2004; Radtke et al. 2004).

Of these models, the input–output technique is well used in the study of fisheries, likely because of the relative ease of computation and accessibility of results (Bhat and Bhatta 2006; Hoagland et al. 2005; Leung and Pooley 2001). Results from an input–output study can be used to predict the outcome of a marginal change in demand for a particular good, and they can easily be interpreted and used in a practical manner.

For further reading on input–output tables, refer to references listed below.

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