Marine Policy 161 (2024) 106013

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

A synthesis of socioeconomic and sociocultural indicators for assessing the impacts of offshore renewable energy on fishery participants and fishing communities

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ARTICLE INFO

Keywords:
Offshore wind energy
Fisheries preclusion
Socioeconomic indicators
Sociocultural indicators
Fishery outcomes
Fishery participant vulnerability

ABSTRACT

Offshore renewable energy, particularly wind farms, is rapidly expanding globally and has become an essential component of many coastal nations' decarbonization plans, including the United States. The addition of these physical structures to the marine space may impact fish production and may preclude fishers from traditional fishing grounds - both of which have the potential to affect fisheries outcomes. Understanding the socioeconomic and sociocultural impacts of implementing offshore wind is crucial to determining appropriate mitigation strategies and to developing data collection, monitoring, and adaptive management strategies. This review synthesizes quantitative and qualitative indicators that have been used to assess the impact of fisheries preclusion and shifts in fished species' biomass on fishery participants. By providing a description of the indicator, a list of the datasets required to calculate its value, and a list of studies that used the indicator, this review can serve as a guide to those designing monitoring plans to determine socioeconomic and sociocultural offshore wind impacts.

1. Introduction

Transitioning to renewable energy technology is critical for climate change mitigation and for meeting growing electricity generation demands [1]. Offshore wind energy is a needed complement to solar energy, particularly in temperate countries, as wind energy production peaks during winter months and in the evening when electricity demands are often high. In addition, offshore wind farms (OWFs) can provide comparative advantage to other wind energy projects, as wind speeds are stronger and more consistent than those on land and OWFs can be sited miles from shore, reducing complaints about appearance or noise [2,3]. For these reasons, offshore wind is an attractive renewable energy option and OWFs are rapidly expanding globally, with existing installations in the UK, the North Sea, China, France, and commitments to increase offshore wind development from many countries including the United States, which aims to produce 30 gigawatts from offshore wind, enough to power 10 million homes, by 2030 [4].

The implementation of offshore renewable energy, like other marine activities, may have important implications on ocean ecosystems and the sectors and communities that use these ocean spaces. In particular, fished populations, and the fishers who depend on them, may be affected by the implementation of offshore wind. Potential impacts can be positive or negative, and can change over time.

OWFs may have positive impacts on fished species including adding physical structure to the water column, creating an artificial reef. Possible negative consequences of offshore wind for fish populations include noise and electromagnetic effects, habitat changes, and entanglement risk [2,5]. Mitigation measures for these negative impacts include high contrast rope to reduce entanglement, placement of boulders to create a reef effect and reduce scour, and cable shielding to reduce electromagnetic radiation [2,6,7]. Significant unknowns that remain include how the biological community will respond to changes in oceanographic patterns around OWFs [3,8].

An important consequence of offshore wind development is that

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https://doi.org/10.1016/j.marpol.2024.106013
Received 21 August 2023; Received in revised form 16 November 2023; Accepted 4 January 2024

certain areas may become less accessible to fishing activity. The extent to which fishers are precluded from areas is fishery/fishing gear specific and depends on a number of factors including the wind energy structure (e.g., fixed or floating), wind energy configurations (e.g., how wind turbines are spatially spread throughout the area), and possible fishing gear hazards introduced by the OWFs (e.g., intra-array cables entangling with fishing gears). For these reasons, OWFs may function as de facto marine protected areas (MPAs), a spatial closure tool used to minimize fishing pressure. An MPA effect may lead to positive fisheries outcomes (e.g., increases in catch) by building up biomass of overexploited species and contributing to fish catch in fished areas via adult spillover and larval subsidies [9–13]. Conversely, MPAs can lead to negative fisheries outcomes by reducing fishing area or by displacing fishing effort to unproductive fishing grounds, potentially further from port [14].

The ecological effects of OWFs, together with fisheries preclusion, may impact economic, social, and cultural outcomes for fishers and fishing communities. These impacts range from changes in individual fishers' income, to shifts in the number of shoreside support businesses, to the reinvention of coastal communities' culture [22,37,72]. Understanding how OWF development will affect fishers and fishing communities is crucial for understanding potential tradeoffs, identifying participants who are particularly vulnerable to OWF impacts, and determining appropriate monitoring and mitigation strategies in scenarios where offshore wind implementation may result in negative socioeconomic and sociocultural consequences.

Knowledge of the socioeconomic and sociocultural impacts of OWFs is still developing, given the technology's recent expansion. The current state of the literature was reviewed by Hogan et al. and the report indicated an immense amount of research is still needed to understand all potential impacts [15]. However, fisheries displacement is not unique to ocean-based renewable energy development – there is a wealth of literature on the socioeconomic impacts of marine spatial closures (e.g., MPAs) and climate-induced shifts in fishing grounds [19,25,29,37,47]. The methods used and the lessons learned from this research can be used to inform future research on the socioeconomic and sociocultural impacts of OWFs.

The majority of research on fisheries displacement uses indicators – analytical tools used to track changes in ecological, economic, social, and cultural conditions. Common indicators include changes in catch, revenue, time spent fishing, economic well-being, and shoreside infrastructure. This review synthesizes socioeconomic and sociocultural indicators discussed throughout offshore renewable, spatial closure, and climate change literature and describes the data requirements and potential data sources for these indicators. This review is the first to synthesize all indicators that can be used to determine the implications of offshore wind energy to the fishing sector. We aim to provide a guide for those developing studies to assess the socioeconomic, sociocultural, and equity impacts of offshore wind development and to inform future data collection efforts.

2. Methods

Offshore wind is a relatively new renewable energy solution, and scientific studies on its effects are limited. Therefore, we conducted a systematic review of both peer-reviewed and gray literature to identify studies that used socioeconomic and sociocultural indicators to assess the impact of fisheries displacement.

The review focused on three primary causes for fisheries displacement: 1) vessel preclusion from marine renewable energy sites; 2) marine spatial closures; and 3) shifts in fishery operations due to climate change. We included literature on spatial closures because they are a common fisheries management tool and are comparable to fisheries preclusion from OWFs. Our search focused on the most common types of closures – MPAs, Rockfish Conservation Areas, National Monuments, and Essential Fish Habitat. We included literature on climate-induced fisheries shifts because of the large body of work on fishery displacement as species' abundances and distributions shift.

The search was completed in Google Scholar using the search terms listed in Table 1.

Articles published from January 2000 through November 2023 were included. For each search term, the first ten articles were screened for relevance and pertinent publications were read in detail; this close reading included checking the paper's references for additional studies to review. Finally, publications identified through expert consultation were incorporated into the analysis. In total, 67 studies were analyzed.

The identified socioeconomic and sociocultural indicators were organized into nine categories: 1) changes in catch and revenue, 2) changes in time spent at sea and distance to port, 3) crowding and safety concerns, 4) shifts in fishing costs, 5) shifts in profit, 6) livelihood and economic well-being effects, 7) community level impacts, 8) cultural and identity consequences, and 9) indicators that assess fishers' differential vulnerability.

The analytical methods used in the studies were both qualitative and quantitative, examining both direct and indirect impacts of fisheries preclusion. For each indicator category, we provide descriptions of the indicators, the methods and datasets needed to calculate their value, and an example that is representative of the way indicators can be used to assess socioeconomic and sociocultural impacts of OWF development.

The first eight categories of socioeconomic and sociocultural indicators are described with a unique identifier (N1-N37) in parentheses for easy reference to Table 2. Indicators in the final category, assessing fishers' differential vulnerability to fisheries preclusion, are described with a unique identifier (V1-V12) for easy reference to Table 3. Data sources listed in Tables 2 and 3 are broken out into three categories: publicly available data, confidential data, and new data that can be collected. The data sources, particularly the confidential sources, are focused on U.S. datasets, but the metrics can be used in a wide range of contexts.

Table 1
List of search terms used in Google Scholar to identify studies examining the socioeconomic impacts of fisheries displacement. The search was conducted from February to November 2023.

Type of Displacement	Terms Used
Renewable Energy	"fisheries renewable energy" AND "fisheries offshore wind" AND "fisheries offshore wind farms" AND "socioeconomic fisheries renewable energy" AND "socioeconomic fisheries offshore wind" AND "socioeconomic fisheries offshore wind farms" AND "socioeconomic indicators ocean renewable energy" AND "socioeconomic indicators offshore wind" AND "socioeconomic indicators offshore wind farms" AND "fishing activity renewable energy" AND "fishing activity offshore wind" AND "fishing activity offshore wind farms" AND "fisheries vulnerability renewable energy" AND "fisheries vulnerability offshore wind"
Spatial Closures	"socioeconomic fisheries mpa" AND "socioeconomic fisheries marine protected area " AND "socioeconomic fisheries rockfish conservation area" AND "socioeconomic fisheries essential fish habitat" AND "spillover mpa" AND "spillover marine protected area" AND "spillover rockfish conservation area" AND "spillover essential fish habitat" AND "fisheries vulnerability MPA" AND "fisheries vulnerability marine protected area" AND "fishing activity mpa" AND "fishing activity marine protected area" AND "fishing activity rockfish conservation area" AND "fishing activity national monument" AND "fishing activity essential fish habitat" AND "fisheries mpa" AND "fisheries marine protected area" AND "fisheries rockfish conservation area" AND "fisheries national monument"
Climate Change	"social-ecological fisheries climate vulnerability assessments"
General	"fishing vessels effort displacement"

Table 2
Quantitative and qualitative indicators used to assess impacts that may occur with the creation of offshore wind areas. Each row lists the calculation and datasets needed to determine the change in the indicator value once fishery preclusion occurs. Descriptions of the datasets are separated into three categories: publicly available, confidential, and data to collect. Data listed in the "New data collection" column represent data that can be collected by wind energy area lessees. For indicators that are assessed using solely qualitative methods, example questions researchers can ask fishery participants are provided. The final column is a list of studies that used the indicator to examine fishery participant responses to the creation of renewable energy areas, the implementation of spatial closures, and shifts in species' distributions with climate change.

ID	Indicator	Unit (s)	Calculation	Dataset options			Ref.
				Publicly available	U.S. confidential	New data collection	
Changes in catch and revenue							
N1	**total catch**	lbs/kg/# caught per year if #, must account for potential change in fish size, i.e., with # caught by length class		1) Sea Around Us global catch database (entire regions, not spatially explicit); 2) RAM Legacy Stock Assessment Database (RAM); 3) FAO Global Capture Production Database	1) landing receipts/ fish ticket data (from federal or state agency such as California Department of Fish and Wildlife (CDFW)); 2) logbook records (e.g., U.S. highly migratory species hook and line logbooks); 3) observer program data	Before-After Control-Impact (BACI) onboard experimental fishing (to assess if closed areas change fished species' biomass)	Renewable Energy: [17,20, 22–24,27, 49–52] Spatial Closure: [11, 25,29, 53–59,87, 88] Climate Change: [35, 47]
N2	**% of region-wide landings from closed area**	catch inside area versus regional catch (%)	$\frac{catch_i}{catch_r} * 100$ where *i* is inside and *r* is regional	total catch (N1) data	total catch (N1) data	total catch (N1) data	Renewable Energy: [17, 20] Spatial Closure: [38]
N3	**total revenue (ex-vessel value)**	$	$catch * p$ where *p* is the unit price of species	total catch (N1) + price: Sea Around Us database	total catch (N1) data + price: landings receipts/fish ticket data		Renewable Energy: [23,27,44, 60,61] Spatial Closure: [27,28,38, 54,57,59,62, 87,88] Climate Change: [35]
N4	**% of region-wide revenue from closed area**	revenue inside area versus regional revenue (%)	$\frac{catch_i * p}{catch_r * p} * 100$ where *i* is inside and *r* is regional, and *p* is the unit price of species	total revenue (N3) data	total revenue (N3) data		Renewable Energy: [44,61] Spatial Closure: [38]
N5	**catch quality**	size of fish caught		total catch (N1) data	total catch (N1) data	total catch (N1) data surveys or interviews to assess perceived change in catch quality	Spatial Closure: [55]
N6	**catch composition species diversity**	1) species richness (# of species caught) 2) relative abundance of each species 3) Shannon Index 4) Simpson Index	Simpson Index= $\sum_{i=1}^{s} p_i \ln\ln\ p_i$ Shannon Index = $\frac{1}{\sum_{i=1}^{s} p_i^2}$ where *p* is the # of individuals of one species divided by the total # of individuals found	total catch (N1) data	total catch (N1) data	surveys or interviews to assess perceived change in catch diversity	Renewable Energy: [16,52,63] Climate Change: [47]
N7	**catch per unit effort (CPUE)** **landings per unit effort (LPUE)** **catch per unit area (CPUA)**	e.g., lbs-per-1000 hooks, lbs-per-set, lbs-per-trip, etc.	Use regression and difference in difference analyzes to ensure change not explained by other factors		1) logbook, observer; 2) fish ticket/landing receipt data merged with VMS (vessel monitoring system) or AIS (automatic	BACI onboard experimental fishing to assess if closed areas change fished species' biomass	Renewable Energy: [20,21,23, 24] Spatial Closure: [11, 19,25,28,38, 54,59,62]

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Table 2 (*continued*)

ID	Indicator	Unit (s)	Calculation	Dataset options			Ref.
				Publicly available	U.S. confidential	New data collection	
					identification system) data		
N8	**value per unit effort (VPUE)**	e.g., $-per-trip	$\frac{catch*p}{effort}$ where p is the unit price of species	CPUE/LPUE/ CPUA data (N7) + price: unit price data found in Sea Around Us database	CPUE/LPUE/ CPUA (N7) + price: landings receipts/fish ticket data		Spatial Closure:[30]
N9	**value per unit fuel (VPUF)**	$	$f_{\max} = 3.976 + 0.236kW$ where $f_{\max}$ is max fuel consumption and kW is engine power $f_{tow} = 0.9 * f_{\max}$ where f_{tow} is fuel consumption while fishing $f_{steam} = \frac{f_{\max}}{s_{\max^3}} * s^3$ where f_{steam} is fuel consumption while steaming at a given speed (s) $f_{total} = f_{tow}h_i + f_{steam}h_j$ where f_{total} is total trip fuel consumption. h_i is hours spent fishing and h_j is hours steaming per trip $VPUF = \frac{catch*p}{f_{total}}$ where p is the unit price of species	VPUE data (N8)	VPUE data (N8)		Renewable Energy:[27] Spatial Closure:[64, 87] Calculation: [65]
Changes in time spent on the water and in distance to port							
N10	**time at sea**	hours or days			1) logbook; 2) VMS; 3) AIS; 4) observer program; 5) Global Fishing Watch	surveys or interviews to assess perceived change in time at sea	Renewable Energy: [22,23] Spatial Closure:[87]
N11	**steaming time/ distance traveled**	meters			time at sea data (N10)	surveys or interviews to assess perceived change in steaming time	Renewable Energy:[23] Spatial Closure:[87]
N12	**fishing effort**	time fishing (hours)		Global Fishing Watch	time at sea data (N10)	surveys or interviews to assess perceived change in fishing effort	Renewable Energy: [17,20,23, 24,52,60] Spatial Closure: [25,27–30, 53,57,59,66, 87] General:[67]
N13	**relative fishing effort**	effort inside area versus regional fishing effort	$\frac{effort_i}{effort_r} * 100$ where i is inside and r is regional, and *effort* is fishing hours	fishing effort data (N11)	fishing effort data (N11)	fishing effort data (N11)	Renewable Energy:[60] Spatial Closure: [11,29,66]
N14	**number of fishing trips**	#			1) landing receipts/ fish ticket data; 2) logbook; 3) VMS; 4) AIS; 5) observer; 6) Global Fishing Watch	time at sea data (N10)	Renewable Energy:[23] Spatial Closure: [27,29,30, 57,62,87, 88]
N15	**primary landing port**	# of trips from each port			1) landing receipts/ fish ticket data; 2) VMS; 3) AIS; 4) Global Fishing Watch		Spatial Closure: [28,38] Climate Change:[47]
Competition and safety concerns							
N16	**competition (vessel density or crowding)**	1) Lloyd's index of mean crowding 2) vessels per square mile (#/mi^2)	1) crowding= $\sum_{j=1}^{n}\frac{f_j^2}{f_j}$ - 1 where f is number of vessels in jth cell	Global Fishing Watch	1) logbook; 2) VMS; 3) AIS	1) drone surveys; or 2) surveys, interviews, focus groups to assess perceived change in vessel density	Renewable Energy:[22, 34,50,68] Spatial Closure:

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Table 2 (*continued*)

ID	Indicator	Unit (s)	Calculation	Dataset options			Ref.
				Publicly available	U.S. confidential	New data collection	
							[29–31,55, 57]
N17	**collision and capsizing risk**	# of vessel accidents		National Transportation Safety Board marine accident reports	1) logbook; 2) VMS; 3) AIS; 4) observer program; 5) Global Fishing Watch		Renewable Energy:[32]
N18	**trips during dangerous conditions**	1) # of trips occurring during bad weather (e.g. wind speed) 2) number of trips in open water 2) number of trips in contaminated waters 3) fisher's perceived change in safety 4) # of vessel accidents		# of fishing trips data (N17) + weather data: historical weather reports from National Weather Service contamination data: State Water Quality Control Boards open water data: NOAA NCEI Seafloor mapping database	# of fishing trips data (N17) + weather data: see publicly available data	surveys or interviews to assess perceived change in safety	Renewable Energy: [22,34,69] Spatial Closure: [31,55]
Shifts in fishing costs							
N19	**fixed costs (insurance, moorage slip costs)**	$				surveys, interviews, or focus groups	Renewable Energy: [23]
N20	**capital expenses (change in gear type, new license)**	$				surveys, interviews, or focus groups	Renewable Energy: [34,52]
N21	**variable costs (fuel, vessel repair/ maintenance, captain and crew share)**	$	$Fuel\ cost = P_f * f_{total}$ where P_f is fuel price and f_{total} is total fuel consumption. f_{total} calculation is listed under calculator for VPUF (N9)		VPUE data (N8) + fuel price: US Energy Information Administration	surveys, interviews, or focus groups	Renewable Energy: [22–24,44] Spatial Closure: [27,28,31, 41,55] Climate Change:[35]
N22	**Average fleet cost (total cost divided by catch)**	$ per lbs/kg/# caught per year	$\frac{Total\ cost}{Catch}$		total catch data (N1) + cost data (N18)	total catch data (N1) + cost data (N18)	Renewable Energy:[23]
Shifts in fishery profit							
N23	**profit**	$	$revenue - cost$		revenue data (N3) + cost data (N18)		Spatial Closure:[57]
N24	**gross value added**	$	$catch * p - fuel\ cost$ where p is the unit price of species	VPUE data (N8)	VPUE data (N8)	VPUE data (N8)	Renewable Energy:[27] General:[64]
N25	**resource rent**	$	$revenue - cost - subsidies$	revenue data (N3) + cost data (N18) + subsidies: Sea Around Us subsidies database			Climate Change:[35]
Livelihood and economic well-being effects							
N26	**fishers income**	$	$\sum_{j=1}^{n}(c_j * w_j)$ where c is catch, w is the wages per tonne of catch for gear type j		U.S. Census Bureau restricted-use data or total catch data (N1) + wage data: see new data collection	total catch data (N1) + surveys, interviews, or focus groups to assess wages per gear type or yearly income	Renewable Energy:[22] Climate Change:[35] General:[67]

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Table 2 (*continued*)

ID	Indicator	Unit (s)	Calculation	Dataset options			Ref.
				Publicly available	U.S. confidential	New data collection	
N27	**entrance and exit (# of fishers or # of vessels)**	# of fishers licenses or # of unique vessels			vessels: 1) commercial vessel permit data; 2) logbook; 3) landing receipts/fish ticket fishers: commercial fishing license data	surveys or interviews	Renewable Energy: [22,52] Spatial Closure: [29,57,66, 88] General:[67]
N28	**access and ability to switch to alternative economic opportunities**	qualitative				distance to nearest major city or survey, interviews, or focus groups example question: “If fishing becomes unprofitable, what employment opportunities are available for you?”	Renewable Energy: [22,40,69, 73,74,76] Spatial Closure: [28,31,43] Climate Change:[37, 79] General:[41]
N29	**economic well-being**	qualitative				surveys, interviews, or focus groups example question: “Has your economic status improved or decreased since operation of the wind energy area began? … much better, better, no change, worse, much worse”	Renewable Energy: [73,74,76] Spatial Closure: [28]
Community level impacts							
N30	**total income generated in the local county economy from fishing**	$	*ex vessel value* ∗ *multiplier* where multiplier is income to ex-vessel multiplier	revenue data (N3) + Reports of economic multipliers for fisheries (e.g. Hackett et al. 2009 for California fisheries)			Spatial Closure:[38]
N31	**fishing community infrastructure (i.e., shoreside services)**	qualitative				surveys, interviews, focus groups, oral histories example question: “How many fishing support services are located at your primary landing port?”	Spatial Closure:[78] General:[41] Climate Change:[37]
N32	**tourism**	qualitative				surveys or interviews example question: “Has tourism increased or decreased since the development of OWFs?”	Renewable Energy: [42,74–76, 80,81,82]
N33	**food security / availability of local seafood / market structure**	qualitative				surveys, interviews, or focus groups example question: “How much demand is there for your catch locally?”	Spatial Closure:[43, 78] General:[41] Climate Change:[79]
Cultural and identity consequences							
N34	**place-based identity / place attachment**	qualitative				survey, interviews, or oral histories example	Renewable Energy: [70–77]

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Table 2 (*continued*)

ID	Indicator	Unit (s)	Calculation	Dataset options			Ref.
				Publicly available	U.S. confidential	New data collection	
						questions: “Why are you a fisherman?” “Do you live in this area seasonally or year round?”	Spatial Closure:[83] Climate Change:[37]
N35	**job satisfaction**	qualitative				surveys and interviews example question: “Are you satisfied with the income you currently make from fishing?”	General:[41]
N36	**traditional knowledge / cultural heritage**					surveys, interviews, or oral histories example question: “Talk to me about your history in fishing.”	Renewable Energy:[22, 72] Spatial Closure:[78] General:[67]
N37	**mental health**					surveys or interviews example question: “Rate your anxiety level pre- and post-OWF development … very high, high, low, very low”	Renewable Energy:[22]

3. Results

3.1. Range of identified indicators and assessment methods

The most common indicators encountered in the literature are direct economic impacts that can be measured pre and post-closure using straightforward empirical analyses. The majority of these indicators fall under the following categories: changes in catch and revenue, changes in time spent at sea and distance to port, and changes in competition and safety. Empirical analyses quantify these impacts using data reported by vessel operators and regulatory organizations or using data generated from experimental fishing. Empirical analyses are used pre-OWF development to examine the extent of economic activity within the proposed area and post-OWF development to determine if any changes in economic indicators were observed.

Qualitative methods are another tool used in studies examining the consequences of fisheries preclusion. These methods include developing surveys, conducting interviews, organizing focus groups, and requesting oral histories from fishery participants. By going into communities and hearing directly from fishery participants, the scope of an impact analysis increases – changes in economic, social, and cultural indicators can be evaluated. For example, researchers can not only learn about the percent change in fishers’ income, but can also hear how their economic well-being and identity has shifted in response to OWF development [22].

Surveys were the most frequent qualitative tool used in the literature. These questionnaires can be distributed in person or via mail/email and can include binary yes/no, likert scale (which ask for degree of agreement or disagreement with a statement), and open ended questions [40]. But, interviews, oral histories, and focus groups allow researchers to thoroughly learn about fishery participant concerns [41]. Interviewers can ask general questions around themes that allow for discussion, encouraging the interviewee to freely express their opinions [41]. Oral histories are similar, but questions focus on the interviewee’s family history in fishing. Focus groups are useful, because attitudes, feelings, and beliefs might only be revealed through conversations with peers, rather than through discussions with researchers [41]. Recruitment of participants ranges from drawing from a random sampling of commercial fishers from census databases to snowballing sampling (i.e., participants asked to identify other potential interviewees). Researchers often use qualitative coding (i.e., systematically coding excerpts from transcripts) to discover themes and patterns from interviews, oral histories, and focus groups.

These qualitative research techniques were often used alongside empirical analyses to deepen understanding of economic effects, to elucidate community wide impacts, and to provide context for unexpected results. Qualitative methods are essential when evaluating changes to indicators within the following categories: shifts in fishing costs, shifts in profit, livelihood and economic well-being effects, community level impacts, and cultural and identity consequences.

For many studies identified in the literature search, only potential impacts to indicators were examined. Stakeholders often want to understand potential effects before a spatial closure goes into effect or an OWF is developed, to inform planning and mitigation efforts. Fishers and community members can be interviewed about plausible impacts to their safety, livelihood, and community with OWF development. Empirical analyses can calculate the relative proportion of catch, revenue, fishing effort, etc. that currently occurs within proposed OWFs. If the proportion is high, socioeconomic impacts are assumed to be negative. Studies that examined potential shifts often reported negative impacts of OWF development [17,22,40,44,60]. However, for the few studies that measured indicator values pre- and post-OWF development, neutral to positive socioeconomic effects were observed [20,24,50].

Unlike empirical analyses and qualitative methods, predictive models can forecast changes to socioeconomic indicators before OWF development begins. The majority of these models are coupled social-ecological models that predict changes in indicator values based on 1) changes in target species’ biomass and 2) changes in individual fisher or entire fleet behavior due to fisheries preclusion [23,27,51]. Predictive models that incorporate information from both empirical and

Table 3
Indicators used to assess which fishery participants may be the most impacted by the creation of offshore wind areas. The datasets needed to assess the most vulnerable groups are separated into three categories: publicly available, confidential, and data to collect. The final column is a list of studies that used the indicator to reveal the most vulnerable fishery participants.

ID	Indicators used to assess most vulnerable/ who will be most affected	Dataset options			Ref.
		Publicly available	U.S. confidential	New data collection	
Vessel attributes					
V1	**gear type / target species**	Global Fishing Watch	1) landing receipts/fish ticket data; 2) observer	surveys or interviews	Renewable Energy: [17,27,44] Spatial Closure: [29,85] General: [67]
V2	**vessels specifications (age, length, engine power, crew #)**	Global Fishing Watch	1) commercial vessel permit data; 2) logbook data	surveys or interviews	Renewable Energy: [17,22,27,34,44,86] Spatial Closure: [29,38,85] General: [67] Climate Change: [47]
V3	**number of target species / number of permits associated with vessel**	Global Fishing Watch	1) landing receipts/fish ticket data; 2) observer; 3) vessel permit data	surveys or interviews	Renewable Energy: [86] Spatial Closure: [85]
V4	**vessel home port / resident vs nonresident vessel / fidelity to historic fishing grounds**		For vessels: 1) commercial vessel permit data; 2) logbook; 3) landing receipts/fish ticket	surveys or interviews	Renewable Energy: [27,86] Spatial Closure: [30,62]
Fishery participant attributes					
V5	**dependence on fishing (fishers or fishing community with a certain % of income coming from fished species)**	U.S. Census restricted-use data (see U.S. confidential) + datasets used to calculate total revenue (N3)	U.S. Census restricted-use data + datasets used to calculate total revenue (N3)	surveys or interviews	Renewable Energy: [34,86] Spatial Closure: [38,78,84,85] Climate Change: [37,46,79]
V6	**number of dependents supported by fishers' income**		U.S. Census restricted-use data	surveys or interviews	Spatial Closure: [38,85]
V7	wealth reserves			surveys or interviews	Climate Change: [37]
V8	**underrepresented groups: BIPOC, women, single parents, persons below poverty, persons with a disability/poor health, persons without a vehicle, persons without high school diploma**		U.S. Census restricted-use data	surveys or interviews	Climate Change: [46] Spatial Closure: [84,85] General: [41,67]
V9	**years spent fishing / fishers age**		Commercial vessel permit data, commercial fishing license data, U.S. Census restricted-use data	surveys or interviews	Renewable Energy: [34] MPA: [38] General: [67]
V10	**previous employment other than fishing**			survey or interviews	Spatial Closure: [84]
V11	**ability to fish out of other ports/boats**			survey or interviews	Spatial Closure: [85]
V12	**member of fisher association or co-op / fishers with a partners**			survey or interviews	Spatial Closure: [84,85]

qualitative analyses pre-OWF development are the most comprehensive, predicting changes from number of fishing trips, to revenue, to total costs at the fleet level [23].

In the following sections, each identified indicator is described in more detail alongside the most common method used to assess shifts in its value. The sections flow from direct at sea impacts, to the economic consequences of changes experienced at sea, to indirect effects on fishing communities' economy, identity, and culture. Finally, we discuss how researchers have used indicators to assess the differential vulnerability of fishery participants to fisheries preclusion. Although the indicators identified in the literature are outlined as distinct attributes in the following sections, all indicators interact. For example, a change in the amount of time spent fishing can impact the number of fishing trips, the fuel costs, etc.

3.2. *Changes in catch and revenue*

3.2.1. *Catch and revenue*

Two of the most common indicators used to assess the impact of closed areas on fishery participants are changes in catch and revenue. Many studies examining the impact of fishery preclusion first look at what percent of region-wide landings are caught within the proposed closed area (N2). If significant, the change in total catch (N1), in weight or number of fish caught, can either be empirically assessed or modeled. Percent of region-wide revenue coming from the closed area (N4) and change in total revenue (N3) are calculated by simply multiplying catch by the unit price for the species. Catch quality (e.g., size of catch; N5) and catch composition (i.e., species richness or species evenness; N6) may also change after an area closure, which can impact vessel revenue and signal the potential for new fishery development in the region [16]. New fisheries may result from offshore wind farm development, such as tuna fisheries, when wind farm structures aggregate enough tunas and small pelagics to make these fisheries profitable [5].

To empirically calculate changes in catch and revenue, annual region-wide catch estimates (e.g., RAM Legacy Stock Assessment Database) and unit price datasets (e.g., Sea Around Us Database) are publicly available. However, these datasets are likely not at the spatial scale needed to adequately identify effects from an individual OWF. Three types of confidential datasets are typically used to examine port-level shifts in catch and revenue: 1) commercial landing receipts (i.e., fish ticket data with unit price listed); 2) vessel logbook data, which are industry reports documenting fishing activity submitted to federal or state agencies; and 3) national observer program data collected by independent biological technicians onboard commercial vessels. Berkenhagen et al. used logbook data to examine the percent of region-wide catch landed within planned OWFs in Germany's EEZ and predicted significant loss in fishing opportunity for flatfish fishing vessels, which harvested 60% of Turbot, Plaice, Dab, and Brill catch within proposed OWFs [17].

3.2.2. Catch per unit effort (CPUE), value per unit effort (VPUE), value per unit fuel (VPUF)

Fisheries preclusion can also impact catch rates [18]. If biomass is lower in the alternative fishing grounds, then catch per unit effort (e.g., lbs per haul; N7) would likely decrease (except for species that exhibit hyperstability, where CPUE is stable across a broad range of fish biomass levels); this would reduce the value per unit effort (e.g., $ per haul; N8) and value per unit fuel (e.g., $ per liter fuel consumed; N9). Value per unit fuel would also decrease if vessels are forced to travel further to alternative fishing grounds (the implications of increased travel time are examined in Section 3.3). If the closed area results in a spillover effect, a positive change in the three indicators may be observed [11,19]. Like catch and revenue, these indicators can be empirically assessed or modeled pre-closure. Catch per unit effort (CPUE) and value per unit effort (VPUE) can be calculated from logbook data or from landings receipt data merged with vessel monitoring system (VMS) data or Automatic Identification System (AIS) data. VMS and AIS are technologies that track vessel position and speed; when merged with landings receipt data, the catch per unit time and the revenue per unit time can be calculated. For example, Belgian logbook data merged with VMS data showed that catch and landings per unit effort (similar to CPUE, lbs per landing) did not decrease in the region after the development of offshore wind farms [20]. In fact, for Plaice, catch and catch rate increased around some of the OWFs [20]. To determine value per unit fuel (VPUF), fuel consumption estimates are also needed, which can be calculated using engine power (kW) information found in logbook data or commercial vessel registration data. Calculations for CPUE, VPUE, and VPUF are listed in Table 2.

For changes in catch and CPUE, wind energy lessees can also choose to conduct their own monitoring studies rather than obtaining confidential data from state or federal agencies. The majority of monitoring studies examining the impact of OWFs on biomass use a before-after-control-impact (BACI) design [9,21,22]. In a BACI design, experimental fishing takes place in a control area outside of the OWF and within the proposed OWF (impact area) before construction begins; the same monitoring occurs in the control and impact area post-OWF development. If catch and CPUE have increased at the edge of the OWF relative to the control sites, it indicates spillover is occurring and the OWF could be having a positive impact on commercial fisheries. Wilber et al. used a BACI design to study the change in CPUE of the Block Island Wind Farm in Rhode Island [21]. The seven-year study consisted of monthly demersal trawl surveys and results showed that CPUE only increased for species that were structure-oriented species (e.g., Atlantic Cod and Black Sea Bass) [21].

3.3. Changes in time spent at sea and distance to port

3.3.1. Time at sea, travel time, fishing effort, number of fishing trips

At sea, vessels are either steaming to and from fishing grounds (i.e., travel time; N11) or fishing (i.e., fishing effort; N12). If fishing is precluded from OWFs or if fish aggregate around OWFs, total time at sea (N10) could shift due to changes in steaming time, fishing effort, or both.

Fishers interviewed about the impact of UK offshore wind development believed that the proposed OWFs would increase steaming time, since areas with comparable productivity are further from port, reducing actual fishing time [22]. If trips become longer, the total number of fishing trips could decrease (N14) [23]. Longer trips could also decrease seafood freshness [15]. Pre-OWF development, the relative proportion of fishing effort (N13) that occurs within the proposed locations can be quantified to forecast future impacts.

Monitoring region-wide change in fishing effort is a key way to understand the overall socioeconomic impact of OWFs. But, analyzing spatial shifts in fishing effort reveals the impact of specific OWFs on fished species. Stelzenmüller et al. used VMS to identify areas where pot fishing effort was concentrating before and after construction began on 12 offshore wind farms in the North Sea [24]. At five of the OWFs, fishing effort moved toward the turbines. At one site, fishing only began after wind farm operation began. This indicates closing the area to fishing and adding physical structures to the water aggregated crustaceans and generated a spillover effect [24]. After the establishment of the Channel Islands MPA network in California, lobster fishing effort around the MPAs increased by 250%, resulting in a 225% increase in catch, signifying a spillover effect [25].

Changes in time spent steaming and fishing can be calculated for each fishing trip from VMS or AIS data using the approach detailed in Kroodsma et al. [26]. Global Fishing Watch makes fishing effort data (calculated using VMS/AIS technology) publicly available on their website. Raw VMS and AIS tracks can be requested from Global Fishing Watch or from federal/state agencies. For vessels without VMS or AIS, changes in the five indicators (travel time, fishing effort, relative fishing effort, time at sea, and number of fishing trips) can be calculated from logbook or observer data. In the Baltic Sea, a region where multiple offshore wind farms and new conservation areas are planned, trawlers, gillnetters, and seiners are equipped with VMS and report catch via landings receipts. Bastardie et al. predicted how Baltic Sea fishers' time on the water may change by using VMS data to inform a spatially-explicit, vessel-based bioeconomic model, where vessel activity was simulated and all vessels avoided the proposed closed areas [27]. Vessels spent more time steaming than fishing, which increased total trip length and reduced the number of total trips taken [27]. Even if steaming time and fishing effort shifts, revenue may not be impacted. Despite less efficient trips, Baltic Sea fishers' revenue was predicted to only decrease by 2%, because CPUE for two key target species, Herring and Sprat, increased from spillover effects [27].

3.3.2. Distance to port

If traveling to alternative fishing grounds increases the time spent at sea, vessels may choose to shift their primary landing port (N15) to reduce steaming time. Vessels may also choose to shift their primary landing port to avoid congestion from offshore wind maintenance and operation activities. This could have cascading impacts on shore-side businesses and local county economies. However, there are many reasons why fishers have a preferred landing port. In Hawaii, the creation of an MPA network increased travel time for fishers in the aquarium trade [28]. But, fishers still preferred to launch their boat from the same harbor, because it was closest to the airport, and seawater replenishment is difficult when transporting catch by land [28].

3.4. Crowding and safety concerns

If OWFs are placed in areas with historically high fishing effort, vessels may be forced to concentrate in alternative fishing grounds [17]. This could increase conflict and competition between fishers (N16). The enlargement of the Bornholm MPA in the Baltic Sea forced cod trawlers and herring/sprat trawlers to move into the same fishing grounds; intensive fishing of the smaller alternative grounds reduced CPUE for both fleets [29]. In addition, gear collisions increased between gill netters and cod trawlers [29]. Changes in competition can be quantified using Lloyd's mean crowding index, which is based on the level of co-occupation in a fishing area (Table 2). Lloyd's mean crowding revealed a 28% increase in crowding for the Dutch beam trawl fleet in response to a closed area established to protect cod spawning [30].

Collision and capsizing risk (N17) rises with an increase in vessel density. Both the concentration of vessels on remaining fishing grounds and the addition of offshore wind maintenance vessels into the marine space may increase vessel crowding [15]. If the Coast Guard does not establish a safety zone associated with an OWF, vessels may face an increased risk of striking turbine platforms. Gear entanglement is also a safety concern since it can threaten vessel stability. The National Transportation Safety Board's marine accident reports can be used to assess changes in the rate of vessel accidents. Collision risk with OWF development can also be modeled using VMS and AIS. Copping et al. used AIS data to map current and future vessel routes along the U.S. East Coast and found that planned OWFs in the region only marginally increased the likelihood of vessel accidents [32].

OWF development could also encourage fishing in dangerous conditions (N18) in order to avoid competition or make up for lost revenue, or because safe fishing locations are no longer accessible. Post-OWF development, vessels may take more trips during bad weather, in open waters with larger wave heights, and/or in contaminated waters. Changes in the number of trips taken in these conditions can be quantified with the same datasets used to calculate fishing effort and number of fishing trips. Pre- and post-OWF development, researchers could calculate the number of trips per unit of time that occurred during dangerous conditions. Historical weather data, including wind speed and wave height, are available from the National Weather Service; seafloor depth data are publicly available from the National Center for Environmental Information's Seafloor Mapping project; and maps of water quality (e.g., harmful algal blooms) are often publicly available from State Water Resources Control Boards.

3.5. *Shifts in fishing costs*

3.5.1. *Fixed costs*

OWF development could increase vessel owner's fixed expenses (N19) including insurance costs and moorage costs [23]. Insurance costs may increase if companies believe there will be an increased safety risk, if there may be increased risk of damaging vessels or turbines, or if the average distance to port increases [33]. Moorage and/or slip costs could rise as demand for space in ports increases [15]. Changes in insurance cost can be determined by interviewing vessel owners and/or insurance companies. Changes in moorage and/or slip costs can be calculated by contacting harbor, port, and marina districts and asking for slip prices pre- and post-OWF development. Other fixed costs include vessel permit, fishing license, and quota costs; however, these costs are unlikely to shift in response to OWF development.

If using certain gear types or targeting particular species becomes unprofitable in regions with OWFs, fishery participants may choose to switch into other fisheries. There are significant capital expenses (N20) that accompany this choice including new equipment and new licenses and permits [22]. Interviews or surveys of fishers is the typical way to quantify these switching costs. In South Wales and Eastern England, offshore wind will likely be co-located with crab and lobster fisheries; however, in interviews fishers stated the capital needed to purchase a shellfish license is too high to switch into the more profitable fishery [34]. The total amount of gear switching can be determined by analyzing the change in the number of permits for each gear type in commercial vessel permit data pre- and post-OWF development.

It is possible to predict the break-even catch needed to make the capital expenses essential for switching target species worthwhile. At the boundaries of North Sea wind farms, catch rates of brown crab are increasing relative to brown shrimp CPUE [24]. Stelzenmüller et al. calculated the capital beam trawlers would need to begin pot fishing and the difference in total cost between the two gear types (fuel and maintenance costs are 50% lower for pot fishing) [24]. If beam trawlers can fish brown crab for at least 15 days when the brown shrimp fishery is unprofitable, investing in gear and vessel modifications will be beneficial [24].

3.5.2. *Variable costs*

If time spent at sea changes, fuel and vessel repair/maintenance costs would shift as well (N21) [22,23]. The longer the trip, the more fuel is consumed and the more regular maintenance is needed (e.g., lubrication of mechanical components, gear repair, etc.). Calculating a change in fuel cost requires fuel price data (provided by the U.S. Energy Information Administration) and fuel consumption data (same datasets used to calculate VPUF). Changes in repair and maintenance costs are determined by surveying or interviewing vessel owners [23]. Another variable cost is the captain and crew share of landings revenue. If the average revenue obtained from a fishing trip shifts due to OWF development, the captain and crew share will shift proportionately [23].

3.5.3. *Total cost*

Change in total cost for a vessel within a fishing fleet is determined by summing the fixed and variable costs pre- and post-OWF development [23]. Scheld et al. projected changes in Atlantic surfclam fishery costs with the development of OWFs using a bioeconomic agent-based model [23]. Total fleet costs decreased by 3–11%, because fishing effort decreased. But, this decrease in effort reduced total catch, so the average fleet cost relative to catch ($ per unit landed; N22) actually increased 1–5% [23].

3.6. *Shifts in profit*

Three economic productivity metrics used to assess changes in the profitability of a fishery are profit (N23), gross value added (GVA; N24), and resource rent (N25). GVA is a vessel or fleet's revenue minus the fuel cost [27]. Profit is calculated by subtracting all fishing operation costs from revenue. Mangi et al. obtained cost data from fishers using surveys and found that the establishment of the Lyme Bay, UK MPA minimally affected profits for fishers. Resource rent is an indicator often used in natural resource economics, and it is calculated for fisheries by subtracting costs and subsidies from a vessel or fleet's revenue [35]. Sumaila et al. estimated fisheries US subsidies, which can be used to calculate changes in resource rent [36].

3.7. *Livelihood and economic well-being effects*

Shifts in catch, revenue, and fishing costs have cascading economic effects, ranging from changes to fisher's income to county-wide employment impacts. Fisher income can be calculated from catch data and the wages per unit of catch or ascertained through surveys, interviews, or focus groups [35]. If income decreases (increases) with OWF development, the number of fishers and vessels active in the fleet may also decrease (increase). Entrance and exit of fishers (N27) can be determined by looking at the change in the number of active commercial fishing licenses. Entrance and exit of vessels from the fleet can be revealed by counting the number of unique vessels in logbook or landings receipt data pre- and post-OWF development. According to logbook data, the implementation of the California Rockfish Conservation Area resulted in 67% of high-intensity users (>40% of fishing effort within closed area boundary) exiting the groundfish trawl fishery [37].

If fishers exit the fishing industry, their livelihoods (the capabilities, activities, and assets needed to support one's existence) will be at risk. To predict the resilience of fishers' livelihoods in the face of offshore renewable energy development, the access and ability to switch to alternative employment opportunities (N28) needs to be established. Surveys and interviews can help determine access to and interest in alternative economic opportunities – 57% of fishers surveyed in Ireland said they would be interested in the new employment opportunities that OWFs would create [40]. The ability to switch careers depends on the number of available jobs in the county, the educational requirements, and the fisher's social capital. If social capital is high (i.e., strong community bonds), it may be easier for fishers to transition to alternative markets [37].

Economic well-being (N29), a person's overall standard of living, is affected by shifts in income and employment. To assess a change in economic well-being post-OWF development fishers should be asked whether their economic status was enhanced, maintained, or lowered. Stevenson et al. used a likert scale to ask about fishers' perceived changes in economic well-being post-MPA network formation in West Hawaii, ranging from much worse to much better, with 53% of respondents saying economic status increased post-MPA implementation [28]. The opposite result was found in the US Virgin Islands, where researchers used likert scale questions to assess fishers' perceptions of the expansion of the Buck Island Reef National Monument [31]. The majority of respondents (54%) stated the expansion adversely impacted their ability to support themselves (Q5) [31].

3.8. *Community level impacts*

Changes in fishing activity impacts income and employment throughout an entire fishing community [38]. Economic multipliers are used to determine the total income generated in the local economy from fishing (N30). A change in the total income generated from fishing is calculated by multiplying total revenue by the economic multiplier for each fishery [38]. Reports of economic multipliers are available for most commercially important fisheries (Hackett et al. lists multipliers for all California fisheries) [39]. OWFs also create jobs and opportunities which is important to consider when assessing income and employment impacts to fishing communities.

Shoreside support businesses, seafood processors, and seafood businesses all rely on the health of the fishing industry. OWF development may impact this community infrastructure (N31) if fishing activity changes. For example, 75% of Northern Irish lobster vessel income is within a proposed OWF site; in interviews it became clear that lobster fishers may move their fishing operations to the east coast of England and Scotland post-OWF development [22]. So even if fisher's livelihoods are maintained, Northern Ireland's seaside cultural heritage will be lost if the shoreside businesses that support fishery activity go out of business [22]. Heritage tourism (N32) may decrease with the loss of these fishing related businesses; although tourists may be drawn to OWFs, if they are viewable from shore or easily accessible by boat [42]. An increase or decrease in fishing activity and/or shoreside businesses can also affect the availability of local seafood markets and food security (N33). Kamat used both semi-structured interviews and focus group discussions to determine the impact of Tanzania's Mnazi Bay-Ruvuma Estuary Marine Park on the local community [43]. Community members' main concern was a decrease in food security with the fishing prohibitions in the marine park, with people reporting that they were increasingly experiencing food insecurity, especially individuals whose livelihood depended on fishing [43].

3.9. *Cultural and identity consequences*

Fishery participants' way of life may be affected with OWF development, specifically their place-based identity (N34), job satisfaction (N35), traditional knowledge or cultural heritage (N36), and mental health (N37). Fishing is not only a source of employment, it is the basis for a community's cultural identity and can provide a sense of belonging [91]. Mackinson et al. examined fishers attitudes toward the development of three OWFs in the UK using both questionnaires and face-to-face interviews [22]. They found fishers can have such a strong place-based identity and high job satisfaction that many would choose to remain in the region even if their economic status is negatively impacted by preclusion from traditional fishing grounds [37]. Fishers were concerned about the potential loss of traditional ecological knowledge if they moved fishing grounds and the resulting impact on economic status [22]. The questionnaire showed that these concerns about OWF development negatively affected fishers' mental health [22].

3.10. *Indicators that assess fishers' differential vulnerability*

Often studies that measure changes to the socioeconomic or sociocultural indicators described above examine the average effect of fishery preclusion across entire fleets or communities. Particular fishers or vessel owners/operators' vulnerability to fisheries preclusion may be greater than others within the same fleet [83,86]. There are three dimensions of vulnerability: 1) fishery participants' exposure to preclusion from historic fishing grounds (percent of fishing area lost); 2) the degree to which they are likely to experience harm (i.e., sensitivity); and 3) the ability to adapt to the change [83]. Only by understanding fishery participants' differential vulnerability can management and mitigation strategies address the needs of all stakeholders. Table 3 describes twelve indicators (V1–V12) found in the literature that classify groups of vessels and fishers based on likely differences in their exposure, sensitivity, and adaptive capacity to fisheries displacement. The socioeconomic and sociocultural indicators listed in the previous section can then be calculated for each distinct group (e.g., change in profit for trawlers, purse seiners, gillnetters, longliners, etc.).

3.10.1. *Vessel attributes*

Vessel attributes that affect the vulnerability of vessel owners/operators and crew members to fishery preclusion include: fishing method and gear type (V1); vessel specifications (e.g., vessel age, length, engine power; V2); number of fishing permits per vessel (V3); and home port and historical fishing ground locations (V4). The vessel attributes that make vessel owner/operators and their crew sensitive to change are location and fishery specific. On the U.S. East Coast, OWFs planned in New York and New Jersey are predicted to predominantly reduce catch for clam and scallop dredge vessels greater than 50 ft in length; OWFs planned in Rhode Island and Massachusetts are expected to largely impact catch for pot and gillnet vessels less than 50 ft in length [44]. Adaptive capacity is often greater for vessels that possess multiple fishing permits (V3), vessels that can land a diverse array of species are more flexible and resilient to change [83,86].

Even vessels within the same fleet and with the same specifications can be differentially impacted by fisheries preclusion based on their historical grounds locations and knowledge of alternative fishing locations (V4) [45]. A temporarily closed area in the North Sea reduced the catch rate for beam trawl vessels that didn't regularly fish in the remaining open areas more than for beam trawl vessels that were already fishing those open areas [30].

These types of analyses are possible, because vessel attribute data are available publicly through Global Fishing Watch (vessel nationality, gear type, vessel length, and engine power) and through commercial vessel registration data that can be requested from state fish and wildlife departments (dataset includes vessel home port, length, year built, horse power, and tonnage). Surveys of vessel owners can also be conducted to obtain the same information.

3.10.2. *Fishery participant attributes*

Similar to vessels, individual fishers may be differentially impacted by OWF development. The greater the dependence on fishing (% of income; V5), the lower the wealth reserves (V6), and the more dependents supported by a fishers' income (V7), the more sensitive an individual may be to fisheries preclusion [38,83]. Even small decreases in revenue and increases in cost can have implications to fishing community livelihoods and well-being. This is especially true for fishers that are members of underrepresented groups (e.g., single parents, indigenous communities, persons without a high school diploma; V8) because they can rely heavily on fisheries for their livelihoods and face systemic barriers that limit access to resources that would increase their adaptive capacity [46].

Fishers' adaptive capacity also depends on the number of years spent fishing in the region (V9) and whether they have employment experience other than fishing (V10). Older fishers with a longer history of fishing and no other employment experience may have greater inertia or lower capability of switching into alternative careers [22,84]. Adaptive capacity is often higher for fishers that can work out of multiple ports and/or vessels (V11) and for fishers that are members of a fishing cooperative or that work with partners (V12). Fishers with larger networks and connections have more avenues to help moderate the impacts of fisheries exclusion [83,84].

Data on individual fishers attributes are available through commercial fishing license data that can be requested from state fish and wildlife departments as well as through U.S. census restricted-use data. However, the majority of reviewed studies relied on surveys and interviews to examine the differential vulnerability of fishery participants. Surveys should include demographic survey questions (e.g., age, education, etc.) to support this type of vulnerability analysis.

A study on the response of fishers to rapid warming in the U.S. Northeast found that vessels targeting fluke and hake showed fidelity to historical fishing grounds (V9) [47]. In interviews with fishers, researchers discovered that the lack of mobility was due to financial concerns related to fuel, safety concerns related to vessel size, sociocultural expectations about time spent at home, and a need for traditional knowledge of their fishing grounds [47]. Distinguishing the vulnerability of fishery participants is needed to fully understand how proposed OWFs may impact fishing communities.

4. Conclusions

Developing new offshore renewable energy projects while considering existing fisheries requires understanding socioeconomic and sociocultural impacts so the appropriate mitigation measures and subsequent monitoring programs can be developed. Mitigation measures for OWF development include: 1) avoidance, measures taken to avoid impacts from the outset; 2) minimization, measures to reduce intensity or duration of impacts; and 3) compensation, measures taken to recompense for impacts that cannot be avoided or minimized.

To avoid space-use conflicts, the decision of where to site an OWF requires multiple years of spatial data documenting fishing activity. Having access to space-use data at an appropriate scale and resolution is essential. Although some studies have utilized large global and regional datasets to compute metrics (Table 2), these data may not be appropriate for assessing more localized changes where impacts are more likely to be detected. Datasets with fishing information at local scales, for example logbook and VMS data in the case of the U.S., are often confidential and thus not necessarily available for tracking metrics. Energy project proponents could engage the entities which have access to these confidential datasets via a data-sharing agreement. If cooperation cannot be achieved, real-time surveillance alternatives (e.g., drones, engine noise monitoring) could be employed, although this would not provide information regarding catch, only space-use. If no spatial data on fishing effort are available, species distribution models of harvested species combined with fishing fleet information (such as the number, range, and home port of fishing vessels) could serve as a proxy to identify and avoid theoretical fishing grounds when siting decisions are made, but this approach would not translate well into a monitoring program.

After avoidance, the subsequent measure in mitigation hierarchy involves minimizing or reducing the impacts of OWF development [89]. The design and technology of offshore renewable energy developments varies widely, and this variability will interact with local fisheries to determine the intensity of potential impacts. For example, bottom-founded wind turbines may minimally affect, if at all, trap fisheries, whereas floating wind turbines may preclude all trawl fisheries inside a project footprint and within a buffer zone to reduce gear entanglement risks. Energy project proponents could set up focus groups with fishery participants to help identify appropriate minimization strategies.

Once the details of an OWF are proposed, monitoring programs are necessary to track changes in impacts that cannot be completely avoided or minimized. This guide can be used to help develop monitoring study methodology, descriptions of which are required in U.S. OWF construction and operation plans. The guide can also be used to help support the formation of community benefit agreements, which describe how wind energy lessees will compensate (the last step in the mitigation hierarchy) and support fishing communities impacted by offshore wind development.

Given the potentially large undertaking of collecting the data and information needed for the 49 indicators presented in this study, it will be important for managers to prioritize which indicators to use for monitoring for specific OWF locations. Existing decision frameworks for selecting suites of indicators for fisheries management (e.g. Rice et al. [90]) can be used to help determine the most appropriate indicators for monitoring [90]. This prioritization process could involve stakeholders in the fishing industry and surrounding fishing community, who could help identify indicators that are most important to the people who will be affected by OWFs. Such engagement could increase perceptions of transparency and inclusiveness in the process, which may also lead to more favorable perceptions of offshore wind from stakeholders and reduce resistance to its development.

Once indicators are selected, socioeconomic and sociocultural impact monitoring should begin 1–2 years before offshore wind construction begins and for at least five years post-OWF development [48]. It is crucial to control for confounding factors when designing monitoring plans so that the observed changes in socioeconomic and sociocultural indicators can be attributed to OWF development. In this review, most studies attributed changes in these indicators to fisheries preclusion within OWFs but shifts in port infrastructure and congestion with offshore wind development can have comparable effects. This review can serve as the basis for the creation of a decision support tool that helps stakeholders decide what socioeconomic and sociocultural indicators to use and how to develop mitigation strategies and monitoring plans.

Funding

Study collaboration and funding were provided by the U.S. Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program, Washington, D.C., under Agreement Number M21AC00023. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U. S. Government. Mention of trade names or commercial products does not constitute their endorsement of the U. S. Government.

CRediT authorship contribution statement

Ellen Willis-Norton: Data curation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Tracey Mangin:** Project administration, Formal analysis, Writing – original draft, Writing – review & editing. **Donna M. Schroeder:** Conceptualization, Writing – review & editing, Funding acquisition, Supervision. **Reniel B. Cabral:** Conceptualization, Writing – review & editing, Funding acquisition, Supervision. **Steven D. Gaines:** Conceptualization, Supervision, Funding acquisition, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have inappropriately influenced their work.

Data availability

No data was used for the research described in the article.

References

[1] D. Gielen, F. Boshell, D. Saygin, M.D. Bazilian, N. Wagner, R. Gorini, The role of renewable energy in the global energy transformation, Energy Strategy Rev. 24 (2019) 38–50.
[2] S.M. Maxwell, F. Kershaw, C.C. Locke, M.G. Conners, C. Dawson, S. Aylesworth, A. F. Johnson, Potential impacts of floating wind turbine technology for marine species and habitats, J. Environ. Manag. 307 (2022) 114577.
[3] G. Broström, On the influence of large wind farms on the upper ocean circulation, J. Mar. Syst. 74 (1-2) (2008) 585–591.
[4] US Department of Interior (DOI), Biden-Harris Administration Announces New Actions to Expand U.S. Offshore Wind Energy, 2022 [Press release]. https://www.doi.gov/pressreleases/fact-sheet-biden-harris-administration-announces-new-actions-expand-us-offshore-wind.
[5] A.H. Fayram, A. De Risi, The potential compatibility of offshore wind power and fisheries: an example using bluefin tuna in the Adriatic Sea, Ocean Coast. Manag. 50 (8) (2007) 597–605.
[6] H. Farr, B. Ruttenberg, R.K. Walter, Y.H. Wang, C. White, Potential environmental effects of deepwater floating offshore wind energy facilities, Ocean Coast. Manag. 207 (2021) 105611.
[7] J.K. Petersen, T. Malm, Offshore windmill farms: threats to or possibilities for the marine environment, AMBIO J. Hum. Environ. 35 (2) (2006) 75–80.
[8] S.K. Siedersleben, Numerical Analysis of Offshore Wind Farm Wakes and Their Impact on the Marine Boundary Layer (Ph.D. thesis), University of Köln, 2019, p. 108. ⟨https://kups.ub.uni-koeln.de/10558/1/Siedersleben_2019_Dissertation.pdf⟩.
[9] C. Stenberg, J.G. Støttrup, M. van Deurs, C.W. Berg, G.E. Dinesen, H. Mosegaard, S. B. Leonhard, Long-term effects of an offshore wind farm in the North Sea on fish communities, Mar. Ecol. Prog. Ser. 528 (2015) 257–265.
[10] B.S. Halpern, The impact of marinereserves: do reserves work and does reserve size matter? Ecol. Appl. 13 (1) (2003) 17–137.
[11] S.E. Kerwath, H. Winker, A. Götz, C.G. Attwood, Marine protected area improves yield without disadvantaging fishers, Nat. Commun. 4 (1) (2013) 1–6.
[12] D. Wilhelmsson, O. Langhamer, The influence of fisheries exclusion and addition of hard substrata on fish and crustaceans. Marine Renewable Energy Technology and Environmental Interactions, Springer, Dordrecht, 2014, pp. 49–60.
[13] E. Sala, S. Giakoumi, No-take marine reserves are the most effective protected areas in the ocean, ICES J. Mar. Sci. 75 (3) (2018) 1166–1168.
[14] I. Chollett, S.J. Box, P.J. Mumby, Quantifying the squeezing or stretching of fisheries as they adapt to displacement by marine reserves, Conserv. Biol. 30 (1) (2016) 166–175.
[15] F. Hogan, B. Hooker, B. Jensen, L. Johnston, A. Lipsky, E. Methratta, A. Hawkins, Fisheries and Offshore Wind Interactions: Synthesis of Science, 2023.
[16] L. Bergström, F. Sundqvist, U. Bergström, Effects of an offshore wind farm on temporal and spatial patterns in the demersal fish community, Mar. Ecol. Prog. Ser. 485 (2013) 199–210.
[17] J. Berkenhagen, R. Döring, H.O. Fock, M.H. Kloppmann, S.A. Pedersen, T. Schulze, Decision bias in marine spatial planning of offshore wind farms: problems of singular versus cumulative assessments of economic impacts on fisheries, Mar. Policy 34 (3) (2010) 733–736.
[18] D. Whitmarsh, C. James, H. Pickering, C. Pipitone, F. Badalamenti, Giovanni D'Anna, Economic effects of fisheries exclusion zones: a Sicilian case study, Mar. Resour. Econ. 17 (3) (2002) 239–250.
[19] S. Medoff, J. Lynham, J. Raynor, Spillover benefits from the world's largest fully protected MPA, Science 378 (6617) (2022) 313–316.
[20] A. De Backer, H. Polet, K. Sys, B. Vanelslander, K. Hostens, Fishing activities in and around Belgian offshore wind farms: trends in effort and landings over the period 2006-2017. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Making A Decade of Monitoring, Research and Innovation. Memoirs on the Marine Environment, Royal Belgian Institute of Natural Sciences, 2019, pp. 31–46.
[21] D.H. Wilber, L. Brown, M. Griffin, G.R. DeCelles, D.A. Carey, Demersal fish and invertebrate catches relative to construction and operation of North America's first offshore wind farm, ICES J. Mar. Sci. 79 (4) (2022) 1274–1288.
[22] S. Mackinson, H. Curtis, R. Brown, K. McTaggart, N. Taylor, S. Neville, S. Rogers, A report on the perceptions of the fishing industry into the potential socio-economic impacts of offshore wind energy developments on their work patterns and income, Sci. Ser. Tech. Rep. Centre Environ. Fish. Aquac. Sci. (2006) 133.
[23] A.M. Scheld, J. Beckensteiner, D.M. Munroe, E.N. Powell, S. Borsetti, E. E. Hofmann, J.M. Klinck, The Atlantic surfclam fishery and offshore wind energy development: 2. Assessing economic impacts, ICES J. Mar. Sci. 79 (6) (2022) 1801–1814.
[24] V. Stelzenmüller, A. Gimpel, H. Haslob, J. Letschert, J. Berkenhagen, S. Brüning, Sustainable co-location solutions for offshore wind farms and fisheries need to account for socio-ecological trade-offs, Sci. Total Environ. 776 (2021) 145918.
[25] H.S. Lenihan, J.P. Gallagher, J.R. Peters, A.C. Stier, J.K. Hofmeister, D.C. Reed, Evidence that spillover from marine protected areas benefits the spiny lobster (Panulirus interruptus) fishery in southern California, Sci. Rep. 11 (1) (2021) 2663.
[26] D.A. Kroodsma, J. Mayorga, T. Hochberg, N.A. Miller, K. Boerder, F. Ferretti, B. Worm, Tracking the global footprint of fisheries, Science 359 (6378) (2018) 904–908.
[27] F. Bastardie, J.R. Nielsen, O.R. Eigaard, H.O. Fock, P. Jonsson, V. Bartolino, Competition for marine space: modelling the Baltic sea fisheries and effort displacement under spatial restrictions, ICES J. Mar. Sci. 72 (3) (2015) 824–840.
[28] T.C. Stevenson, B.N. Tissot, W.J. Walsh, Socioeconomic consequences of fishing displacement from marine protected areas in Hawaii, Biol. Conserv. 160 (2013) 50–58.
[29] P. Suuronen, P. Jounela, V. Tschernij, fishers responses on marine protected areas in the Baltic cod fishery, Mar. Policy 34 (2) (2010) 237–243.
[30] J.J. Poos, A.D. Rijnsdorp, An "experiment" on effort allocation of fishing vessels: the role of interference competition and area specialization, Can. J. Fish. Aquat. Sci. 64 (2) (2007) 304–313.
[31] C. Karras, J.J. Agar, Cruzan Fishers' perceptions of the socio-economic and biological performances of marine closures in St. Croix, in: Proceedings of the 61st Gulf and Caribbean Fisheries Institute, 2009.
[32] A. Copping, S. Breithaupt, J. Whiting, M. Grear, J. Tagestad, G. Shelton, Likelihood of a marine vessel accident from wind energy development in the Atlantic, Wind Energy 19 (9) (2016) 1557–1566.
[33] D.M. Hall, E.D. Lazarus, Deep waters: lessons from community meetings about offshore wind resource development in the US, Mar. Policy 57 (2015) 9–17.
[34] T. Hooper, M. Ashley, M. Austen, Perceptions of fishers and developers on the co-location of offshore wind farms and decapod fisheries in the UK, Mar. Policy 61 (2015) 16–22.
[35] V.W. Lam, W.W. Cheung, U.R. Sumaila, Marine capture fisheries in the Arctic: winners or losers under climate change and ocean acidification? Fish Fish. 17 (2) (2016) 335–357.
[36] U.R. Sumaila, A.S. Khan, A.J. Dyck, R. Watson, G. Munro, P. Tydemers, D. Pauly, A bottom-up re-estimation of global fisheries subsidies, J. Bioecon. 12 (2010) 201–225.
[37] J.G. Mason, J.G. Eurich, J.D. Lau, W. Battista, C.M. Free, K.E. Mills, K.M. Kleisner, Attributes of climate resilience in fisheries: from theory to practice, Fish Fish. 23 (3) (2022) 522–544.
[38] V.R. Leeworthy, P. Wiley, E.A. Stone, Socioeconomic Impact Analysis of Marine Reserve Alternatives for The Channel Islands National Marine Sanctuary. National Oceanic and Atmospheric Administration, Silver Spring, MD, 118, 2003.
[39] S.C. Hackett, M.D. Hansen, D. King, E. Price. The Economic Structure of California's Commercial Fisheries, California Department of Fish and Game, 2009, p. 3.
[40] K. Reilly, A.M. O'hagan, G. Dalton, Attitudes and perceptions of fishers on the island of Ireland towards the development of marine renewable energy projects, Mar. Policy 58 (2015) 88–97.
[41] Patricia M. Clay, Lisa L. Colburn, A practitioner's handbook for fisheries social impact assessment, NOAA Tech. Memo. (2020). NMFS-F/SPO-212, 80 p.
[42] T. Smythe, D. Bidwell, A. Moore, H. Smith, J. McCann, Beyond the beach: tradeoffs in tourism and recreation at the first offshore wind farm in the United States, Energy Res. Soc. Sci. 70 (2020) 101726.
[43] V. Kamat, "The ocean is our farm": marine conservation, food insecurity, and social suffering in southeastern Tanzania, Hum. Org. 73 (3) (2014) 289–298.
[44] A.J. Kirkpatrick, S. Benjamin, G.S. DePiper, T. Murphy, S. Steinback, C. Demarest, SocioEconomic Impact of Outer Continental Shelf Wind Energy Development on Fisheries in the U.S. Atlantic. Volume I—Report Narrative. U.S Dept. of the Interior, Bureau of Ocean Energy Management, Atlantic OCS Region, Washington, D.C. OCS Study BOEM 2017–012, 2017, p. 150.
[45] D. Slijkerman, J. Tamis, Fisheries Displacement Effects Related to Closed Areas: A Literature Review of Relevant Aspects. IMARES report. C170/15(1):52. Accessible at: https://core.ac.uk/download/pdf/44419958.pdf.
[46] L.E. Koehn, L.K. Nelson, J.F. Samhouri, K.C. Norman, M.G. Jacox, A.C. Cullen, P. S. Levin, Social-ecological vulnerability of fishing communities to climate change: a US west coast case study, PLoS One 17 (8) (2022) e0272120.
[47] E.A. Papaioannou, R.L. Selden, J. Olson, B.J. McCay, M.L. Pinsky, K. St. Martin, Not all those who wander are lost–responses of fishers' communities to shifts in the distribution and abundance of fish, Front. Mar. Sci. (2021) 8.
[48] R.C. Babcock, N.T. Shears, A.C. Alcala, N.S. Barrett, G.J. Edgar, K.D. Lafferty, G. R. Russ, Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects, Proc. Natl. Acad. Sci. 107 (43) (2010) 18256–18261.
[49] M. Püts, A. Kempf, C. Möllmann, M. Taylor, Trade-offs between fisheries, offshore wind farms and marine protected areas in the southern North Sea–Winners, losers and effective spatial management, Mar. Policy 152 (2023) 105574.
[50] D.A. Carey, D.H. Wilber, L.B. Read, M.L. Guarinello, M. Griffin, S. Sabo, Effects of the block island wind farm on coastal resources, Oceanography 33 (4) (2020) 70–81.
[51] G. Halouani, C.M. Villanueva, A. Raoux, J.C. Dauvin, F.B.R. Lasram, E. Foucher, F. Le Loc'h, G. Safi, E. Araignous, J.P. Robin, N. Niquil, A spatial food web model to investigate potential spillover effects of a fishery closure in an offshore wind farm, J. Mar. Syst. 212 (2020) 103434.

[52] M. Gray, P.L. Stromberg, D. Rodmell, Changes to Fishing Practices Around the U.K. as a Result of the Development of Offshore Windfarms – Phase 1 (Revised). The Crown Estate, 2016. Accessible at: 〈https://www.thecrownestate.co.uk/media/2600/final-published-ow-fishingrevised-aug-2016-clean.pdf〉. ISBN: 978-1-906410-64-3.

[53] J. Lynham, Fishing activity before closure, during closure, and after reopening of the northeast canyons and seamounts marine national monument, Sci. Rep. 12 (1) (2022) 1–21.

[54] J. Lynham, A. Nikolaev, J. Raynor, T. Vilela, J.C. Villaseñor-Derbez, Impact of two of the world's largest protected areas on longline fishery catch rates, Nat. Commun. 11 (1) (2020) 1–9.

[55] M. Pascual, M. Rossetto, E. Ojea, N. Milchakova, S. Giakoumi, S. Kark, P. Melià, Socioeconomic impacts of marine protected areas in the Mediterranean and Black sea, Ocean Coast. Manag. 133 (2016) 1–10.

[56] F. Bastardie, J.R. Nielsen, T. Miethe, DISPLACE: a dynamic, individual-based model for spatial fishing planning and effort displacement—integrating underlying fish population models, Can. J. Fish. Aquat. Sci. 71 (3) (2014) 366–386.

[57] S.C. Mangi, L.D. Rodwell, C. Hattam, Assessing the impacts of establishing MPAs on fishers and fish merchants: the case of Lyme Bay, UK, Ambio 40 (2011) 457–468.

[58] A. Forcada, C. Valle, P. Bonhomme, G. Criquet, G. Cadiou, P. Lenfant, J.L. Sánchez-Lizaso, Effects of habitat on spillover from marine protected areas to artisanal fisheries, Mar. Ecol. Prog. Ser. 379 (2009) 197–211.

[59] R. Goñi, S. Adlerstein, D. Alvarez-Berastegui, A. Forcada, O. Renones, G. Criquet, S. Planes, Spillover from six western Mediterranean marine protected areas: evidence from artisanal fisheries, Mar. Ecol. Prog. Ser. 366 (2008) 159–174.

[60] V. Stelzenmüller, J. Letschert, A. Gimpel, C. Kraan, W.N. Probst, S. Degraer, R. Döring, From plate to plug: the impact of offshore renewables on european fisheries and the role of marine spatial planning, Renew. Sustain. Energy Rev. 158 (2022) 112108.

[61] D.M. King & Associates, Economic Exposure of Rhode Island Commercial Fisheries to the Vineyard Wind Project, 2019.

[62] H.L. Chan, Economic impacts of Papahānaumokuākea marine national monument expansion on the Hawaii longline fishery, Mar. Policy 115 (2020) 103869.

[63] S.B. Leonard, C. Stenberg, J. Stottrup, Effects of the Horns Rev 1 Offshore Farm on Fish Communities: Follow-up Seven Years after Construction. DTU Aqua Report No 246–2011, 2011, p. 99.

[64] I. Maina, S. Kavadas, V. Vassilopoulou, F. Bastardie, Fishery spatial plans and effort displacement in the eastern Ionian Sea: a bioeconomic modelling, Ocean Coast. Manag. 203 (2021) 105456.

[65] F. Bastardie, S. Hornborg, F. Ziegler, H. Gislason, O.R. Eigaard, Reducing the fuel use intensity of fisheries: through efficient fishing techniques and recovered fish stocks, Front. Mar. Sci. 9 (2022) 698.

[66] J. Mason, R. Kosaka, A. Mamula, C. Speir, Effort changes around a marine reserve: the case of the California rockfish conservation area, Mar. Policy 36 (5) (2012) 1054–1063.

[67] S. Engen, V.H. Hausner, G.G. Gurney, E.G. Broderstad, R. Keller, A.K. Lundberg, P. Fauchald, Blue justice: a survey for eliciting perceptions of environmental justice among coastal planners' and small-scale fishers in Northern-Norway, PLoS One 16 (5) (2021) e0251467.

[68] S. Vandendriessche, K. Hostens, W. Courtens, E. Stienen, Fisheries activities change in the vicinity of offshore wind farms. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Learning from the past to Optimise Future Monitoring Programmes, 2013, pp. 81–85.

[69] K.A. Alexander, T. Potts, T.A. Wilding, Marine renewable energy and Scottish west coast fishers: exploring impacts, opportunities and potential mitigation, Ocean Coast. Manag. 75 (2013) 1–10.

[70] A. Russell, J. Firestone, D. Bidwell, M. Gardner, Place meaning and consistency with offshore wind: an island and coastal tale, Renew. Sustain. Energy Rev. 132 (2020) 110044.

[71] M.T. Brownlee, J.C. Hallo, L.W. Jodice, D.D. Moore, R.B. Powell, B.A. Wright, Place attachment and marine recreationists attitudes toward offshore wind energy development, J. Leis. Res. 47 (2) (2015) 263–284.

[72] B. Burkhard, K. Gee, Establishing the resilience of a coastal-marine social-ecological system to the installation of offshore wind farms, Ecol. Soc. 17 (4) (2012).

[73] J. Acheson, Attitudes toward offshore wind power in the midcoast region of maine, Maine Policy Rev. 21 (2) (2012) 42–55.

[74] P. Devine-Wright, Y. Howes, Disruption to place attachment and the protection of restorative environments: a wind energy case study, J. Environ. Psychol. 30 (3) (2010) 271–280.

[75] C. McLachlan, You don't do a chemistry experiment in your best china': symbolic interpretations of place and technology in a wave energy case, Energy Policy 37 (12) (2009) 5342–5350.

[76] J. Firestone, W. Kempton, Public opinion about large offshore wind power: underlying factors, Energy Policy 35 (3) (2007) 1584–1598.

[77] M.J. Pasqualetti, E. Butler, Public reaction to wind development in California, Int. J. Ambient Energy 8 (2) (1987) 83–90.

[78] R.S. Pomeroy, L.M. Watson, J.E. Parks, G.A. Cid, How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas, Ocean Coast. Manag. 48 (7-8) (2005) 485–502.

[79] R. Ruiz-Díaz, X. Liu, A. Aguión, G. Macho, M. deCastro, M. Gómez-Gesteira, E. Ojea, Social-ecological vulnerability to climate change in small-scale fisheries managed under spatial property rights systems, Mar. Policy 121 (2020) 104192.

[80] C.E. Landry, T. Allen, T. Cherry, J.C. Whitehead, Wind turbines and coastal recreation demand, Resour. Energy Econ. 34 (1) (2012) 93–111.

[81] M.B. Lilley, J. Firestone, W. Kempton, The effect of wind power installations on coastal tourism, Energies 3 (1) (2010) 1–22.

[82] J. Firestone, W. Kempton, M.B. Lilley, K. Samoteskul, Public acceptance of offshore wind power: does perceived fairness of process matter? J. Environ. Plan. Manag. 55 (10) (2012) 1387–1402.

[83] C. Chen, D. López-Carr, B.L.E. Walker, A framework to assess the vulnerability of California commercial sea urchin fishermen to the impact of MPAs under climate change, GeoJournal 79 (2014) 755–773.

[84] A.R. Rasheed, A. Abdulla, N.I. Zakariyya, Vulnerability of different types of fishers to potential implementation of a management plan in a marine protected area (MPA) in the Maldives, Mar. Policy 74 (2016) 195–204.

[85] C. Chen, D. Lopez-Carr, The importance of place: unraveling the vulnerability of fisherman livelihoods to the impact of marine protected areas, Appl. Geogr. 59 (2015) 88–97.

[86] B. Hélène, F. Marjolaine, P. Le Floc'h, Vulnerability and spatial competition: the case of fisheries and offshore wind projects, Ecol. Econ. 197 (2022) 107454.

[87] M.C. Rufener, J.R. Nielsen, K. Kristensen, F. Bastardie, Closing certain essential fish habitats to fishing could be a win-win for fish stocks and their fisheries–Insights from the western Baltic cod fishery, Fish. Res. 268 (2023) 106853.

[88] R.L. Hicks, J. Kirkley, I.E. Strand Jr, Short-run welfare losses from essential fish habitat designations for the surfclam and ocean quahog fisheries, Mar. Resour. Econ. 19 (1) (2004) 113–129.

[89] J.P. Clement, A. Belin, M.J. Bean, T.A. Boling, J.R. Lyons, A Strategy for Improving the Mitigation Policies and Practices of the Department of the Interior. A Report to the Secretary of the Interior from the Energy and Climate Change Task Force, Washington, DC, 2014.

[90] J.C. Rice, M.J. Rochet, A framework for selecting a suite of indicators for fisheries management, ICES J. Mar. Sci. 62 (3) (2005) 516–527.

[91] M.C. Ashley, S.C. Mangi, L.D. Rodwell, The potential of offshore windfarms to act as marine protected areas–a systematic review of current evidence, Mar. Policy 45 (2014) 301–309.