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Bycatch in northeast Atlantic lobster and crab pot fisheries (Irish Sea, Celtic Sea and Bristol Channel)

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ABSTRACT

Bycatch in valuable NE Atlantic baited 'pot' fisheries for lobster *Homarus gammarus* and edible crab *Cancer pagurus* has not been well documented, potentially limiting evidence-based management. Using onboard observers supplemented by fishers' ecological knowledge (FEK) we characterised bycatch of fish and larger invertebrates in 10,741 pot hauls around the coast of Wales, UK, over 4 years in all seasons. A total of 1529 fish from 30 species, and around 15 species of invertebrate, were recorded. Bycatch abundance varied seasonally and spatially and was dominated by eight common and widespread taxa comprising six 'core' fish (two catsharks: bullhuss (*Scyliorhinus stellaris*) and smallspotted catshark (*S. canicula*); ballan wrasse *Labrus bergylta*, sea scorpions (*Myoxocephalus scorpius* & *Taurulus bubalis* combined), three-bearded rockling *Gaidropsarus vulgaris*, conger eel *Conger conger*, together 86% of fish abundance), velvet swimming crab *Necora puber* and spider crab *Maja brachydactyla.* Commercially important fish species were only caught in low numbers (3.0% of all fish), with cod *Gadus morhua* the most frequent (1.8% of all fish). Only two species of conservation interest were recorded: the large catshark *Scyliorhinus stellaris* which is locally abundant (assessed by the IUCN *Red List of Threatened Species* as 'Near Threatened' and 'Vulnerable to extinction' at European and global scales respectively), and a single legally retained spiny lobster *Palinurus elephas.* Retention or live release status was recorded for nearly all (96%) of the core fish individuals and varied widely with taxa: sea scorpions (never retained), *Scyliorhinus stellaris* (13% retained), smallspotted catshark, three-bearded rockling, conger eel (44–59% retained), with ballan wrasse having the highest retention (90% of 242 individuals; average of 5.5 individuals retained per trip when present). Observed high spider crab abundance combined with FEK of previous absence or scarcity suggest that this species has increased in northwards range and abundance in recent decades, possibly because of warming seas. No incidents of in-pot mammal or bird entrapment were recorded. The retention of fish for bait is not currently acknowledged in consumer advice or landings data. Possible effects of bait retention on populations of data-poor species which may be vulnerable to overexploitation (e.g., long-lived ballan wrasse) and coastal ecosystems are unknown and warrant further research.

1. Introduction

Sustainable use of marine resources, including fisheries, is one of the UN 2030 Sustainable Development Goals (United Nations, 2022). Bycatch, or the incidental capture of species, is one of the most significant issues facing fisheries management globally (Davies et al., 2009). The extent and magnitude of bycatch varies widely and involves a complex spectrum of biological, ecological, human, technological, economic and spatial dimensions; some fisheries can have negligible bycatch. Bycatch can negatively impact fishers (e.g. by generating costs or reputational damage), as well as commercial species, endangered, threatened and protected (ETP) taxa, and ecosystems (Davies et al., 2009; Dulvy et al., 2014; Gray and Kennelly, 2018; Hall et al., 2000; Kennelly, 1995; Stevens et al., 2000). 'Clean' fisheries with little bycatch therefore offers benefits to both fishers and the ecosystem, and documenting bycatch is a fundamental first step towards this goal.

A number of factors, including legislation and market conditions, are highlighting the need for evidence on, and consideration of, fisheries bycatch. The UK Fisheries Act (UK Government, 2020) has eight objectives relating to fisheries, of which several are particularly relevant to

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bycatch of non-target species. The “sustainability objective” is that fishing activities are environmentally sustainable in the long term, while the “precautionary objective” applies the precautionary approach to fisheries management (i.e. absence of sufficient scientific information is not used to justify postponing or failing to take management measures to conserve target species, associated or dependent species, non-target species or their environment). The “ecosystem objective” is that fishing activities are a) managed using an ecosystem-based approach so as to ensure that their negative impacts on marine ecosystems are minimised and, where possible, reversed, and b) incidental catches of sensitive species are minimised and, where possible, eliminated. The “scientific evidence objective” is that scientific data relevant to the management of fishing activities is collected. The “bycatch objective” includes that bycatch is avoided or reduced, and recorded and accounted for. Bycatch data is also used in sustainable seafood accreditation or ‘eco-labelling’ schemes, such as the Marine Stewardship Council (MSC); accreditation as a well-managed and sustainable fishery requires “*minimising environmental impact and managing fisheries so that other species and habitats within the ecosystem remain healthy*’’, with specific consideration of bycatch, including ETP species (Marine Stewardship Council, 2022). The first fishery certified by the MSC, that of the western Australian rock lobster, had specific conditions placed on it including a need for detailed and consistent reporting of retained species, bycatch, and interactions with ETP species (Bellchambers et al., 2014).

A further driver for the need for evidence on bycatch is that even fisheries gear types which appear to offer limited bycatch potential can have bycatch issues that offer opportunities for improvement. Pole and line fisheries for tuna are broadly considered to have no or negligible bycatch potential, yet they do sometimes catch ETP fauna such as dolphins and sharks (Miller et al., 2017; Cruz et al., 2018). Similarly, a crab pot fishery in Australia was unexpectedly found to be causing significant levels of mortality of a critically endangered shark species (Pillans et al., 2022). Documenting this bycatch provides baseline evidence for any initiatives to minimise its capture in the first place by modifications to fishing practices or gear (e.g. by using bycatch reduction devices). These may be beneficial to fishers, e.g. by reducing sorting times, increasing the proportion of the target catch, or reducing mortality of ETP species that carries reputational risks. Simple and inexpensive modifications to baited pots have been shown to reduce unwanted bycatch of sharks and terrapins while increasing the catch of target species (Roosenburg and Green, 2000; Richards et al., 2018). Together this highlights the value of evidence collected by independent observer monitoring of commercial activities at appropriate spatial and temporal resolution, to facilitate science-based management.

Baited trap (also known as ‘pot’ and ‘creel’) fisheries for crustaceans have inherent characteristics which limit their ability to cause bycatch compared with other gear types, such as their largely static nature resting on the seabed surface and using bait within meshed traps to specifically target benthic decapods. Documented injury and mortality to bycatch fish and invertebrates includes damage or predation caused by other organisms trapped within the confines of the pot, barotrauma to fish from rapid lifting of pots from depth, physiological stress from exposure to warm surface water and air during hauling, physical injury such as crushing and abrasion during handling of pots, increased predation risk upon discarding, and retention for human consumption or bait (Chen and Runnebaums, 2014; Ferter et al., 2015; Anderson et al., 2020; Stevens, 2021; pers. obs.). Commercially important fish species can frequently occur in pot fisheries but this is often unaccounted for in stock assessment; for example, there has previously been concern that lobster pot bycatch has hindered recovery of cod *Gadus morhua* stocks in the northwestern Atlantic (Boenish and Chen, 2020). Drowning of air-breathing vertebrates from entrapment within pots can occur, and in some cases include ETP species such as otters *Lutra lutra* in Scotland, Ireland, England and Norway (Twelves, 1983; Jefferies et al., 1984; Jefferies, 1989, 1993; Kruuk and Conroy, 1991; Landa and Guidos, 2020). Diving seabirds including auks and cormorants have also drowned in pots (Galbraith et al., 1981; Ewins, 1988), and cormorants *Phalacrocorax carbo* were ‘not uncommon’ in north Wales lobster pots in the 1950s (Owen, 2012). Although outside the scope of the present study, ropes used in pot fisheries around Britain and Ireland have entangled ETP marine megafauna such as baleen whales, basking sharks *Cetorhinus maximus* and leatherback turtles *Dermochelys coriacea*, resulting in sublethal and lethal impacts (Bloomfield and Solandt, 2008; Botterell et al., 2020; Northridge et al., 2010; Rya et al., 2016; Leaper et al., 2022).

Pot fisheries for edible (brown) crab *Cancer pagurus* and lobster *Homarus gammarus* are a key component of inshore fisheries across northwestern Europe from Norway to France, including the British Isles and Ireland, with lobster in Wales (UK) alone representing a first sale value of around £ 2.2 m in 2018 (Edwards, 1979; WFA CPC, 2022). Both the fishing industry and a marine conservation organisation broadly agree that bycatch is likely not a significant issue in pot fisheries generally, and Welsh crab and lobster pot fisheries specifically (Seafish, 2022; Marine Conservation Society, 2022a; b). Bycatch “…*is minimal and usually confined to undersized lobsters and various species of crab…any bycatch…can be easily removed from the pot and released back into the sea immediately without harm*” (Seafish, 2022). While these assumptions appear reasonable there appears to be little or no bycatch-specific evidence, and no Welsh-specific evidence, presented to support them (Seafish, 2022; Marine Conservation Society, 2022a; b). This data gap presents a potential barrier to evidence-based sustainable fisheries management.

Thus, there is a need for fisheries-dependent studies on the composition of pot fishery bycatch and whether it is retained or discarded around the northeast Atlantic (and more specifically Wales and the wider region), yet remarkably few are available. The single peer-reviewed study available examined catches in 2489 fisheries-independent pot hauls in the northern Irish Sea (Isle of Man) and recorded 43 taxa, with nearly 75% of bycatch abundance consisting of just six taxa (velvet swimming crab *Necora puber*, small-spotted catshark *Scyliorhinus canicula,* squat lobsters *Galathea* sp., and three echinoderm species), catches of which varied seasonally and spatially, with several species of commercially important fish species also recorded (Öndes et al., 2018). One unpublished study in Welsh waters reporting pot bycatch was very limited in its sample size (144 pot hauls) and spatio-temporal coverage (Pantin et al., 2015a). These authors also included a list of 24 fish and 16 invertebrate taxa mentioned as bycatch by 53 Welsh pot fishers in a questionnaire study, but without further information such as relative abundance. Retention of at least some bycatch for bait has been reported in both Wales and the Isle of Man, but this has not been quantified (Pantin et al., 2015b; Öndes et al., 2018). A handful of other preliminary unpublished studies around the UK further suggest geographical variation in bycatch composition (Lamb, 2011; Wallace and Rae, 2017).

Despite the widespread nature and high value of commercial crab and lobster fisheries in northwestern European waters, there is an almost complete absence of fisheries-dependent data on bycatch, presenting uncertainty to stakeholders including fishers, fishery managers, consumers and conservationists. Here we aim to address this data gap, using Welsh waters of three regional ICES seas as a case study, with the following specific aims: 1) characterise the taxonomic composition and relative abundance of in-pot bycatch; 2) quantify their temporal (seasonal) and spatial variation; 3) quantify the retention and discarding of common bycatch species.

2. Methods

2.1. Study area

Wales has a coastline of around 2120 km which border three ICES regional seas: the Irish Sea (ICES VIIa, north and mid Wales regions in our study, Table 1), the Celtic Sea (ICES VIIg, southwest Wales), and the

Table 1
Sampling effort by location and season. Seasons are spring (March-May), summer (June-August), autumn (September-November) and winter (December-February).

Wales region	ICES region	Area name	Number of observer day trips (number of pot hauls observed)				
			Spring	Summer	Autumn	Winter	Total
North	VIIa Irish Sea	Liverpool Bay	1 (95)	6 (1117)	5 (847)	1 (125)	13 (2184)
		Anglesey 1	-	1 (21)	1 (21)	-	2 (42)
		Anglesey 2	-	1 (25)	-	-	1 (25)
		N Llŷn peninsula 1	5 (613)	8 (427)	5 (425)	2 (185)	20 (1650)
		N Llŷn peninsula 2	-	-	1 (240)	-	1 (240)
		SW Llŷn peninsula 1	-	3 (253)	6 (332)	-	9 (585)
		SW Llŷn peninsula 2	-	2 (165)	-	-	2 (165)
Mid		Cardigan Bay	-	3 (500)	-	-	3 (500)
SW	VIIg Celtic Sea	Pembrokeshire	4 (852)	9 (1784)	4 (509)	2 (126)	19 (3271)
South	VIIf Bristol Channel	South 1	-	1 (198)	6 (920)	-	7 (1118)
		South 2	-	1 (146)	5 (815)	-	6 (961)
Total			10 (1560)	35 (4636)	33 (4109)	5 (436)	83 (10741)

Bristol Channel (ICES VIIf, south Wales) (Fig. 1). To anonymise individual fishers and their fishing territories we here provide broad geographic locations: for north Wales in the region of Liverpool Bay ('Liverpool Bay' used hereafter), the coast of the southern half of the island of Anglesey ('Anglesey'), the northern and southwestern coasts of the Llŷn peninsula ('Llŷn N' and 'Llŷn SW'); in mid Wales, eastern central Cardigan Bay ('Cardigan Bay'); in southwest Wales ('Pembrokeshire'); and in south Wales ('South')(Fig. 1, Table 1).

2.2. Fishery

The lobster and crab fishery around Wales is most active between May and October, although many fishers operate through all four seasons of the year (Pantin et al., 2015b; pers. comms. with fishers). We sampled on commercial vessels 6–11 m in length crewed by one or two fishers undertaking day trips. Most vessel activity was inshore (<6 nautical miles/11.1 km), and usually considerably less than this (including to within a few m of the intertidal/subtidal margin), although a small amount of fishing activity extended up to 12 nautical miles/22 km offshore. Depth fished ranged from approximately 5 to 30 m, in fully marine waters. The fishers we sampled with actively fish around 25–400 pots at any one time, deployed in 'strings' of between 2 and 22 pots, typically fished ('soaked') for around 2–5 days, although sometimes weather and/or tidal conditions prevented hauling pots for periods up to 3 weeks. Soak time did not have a significant relationship with mean bycatch per unit effort in Irish Sea pot fisheries (Öndes et al., 2018), so is not considered further here. Nearly all pots were D-shaped 'parlour' (i.e., containing a compartment preventing escape) types covered in diagonal mesh, with overall size typically around 78 cm length, 40 cm height and 48 cm width, but varying in size (e.g. larger pots of ~90 cm length). The entrance to the pot was either on the side (with soft plastic netting or hard plastic) or the top (with hard plastic), with both types often found on the same string and/or used by the same fisher. Many fishers had voluntarily fitted plastic 'escape gap' panels (80 mm by 45 mm) in the side mesh to allow undersized lobsters (i.e., carapace length of <90 mm) and other bycatch to escape; escape gaps are known to allow the escape of another crustacean which is sometimes harvested, the velvet swimming crab *Necora puber* (Pantin et al., 2015a; various fishers, pers. comm.). Bait was a wide variety of fresh, salted, or rotten fish or fish waste. All fishers targeted high-value lobster (typically with rotten bait), with some fishers also targeting lower-value edible crab, spider crab *Maja brachydactyla* (previously widely known as *M. squinado* in the northeast Atlantic; see Sotelo et al., 2008) and velvet swimming crab (*Necora puber*) to varying degrees.

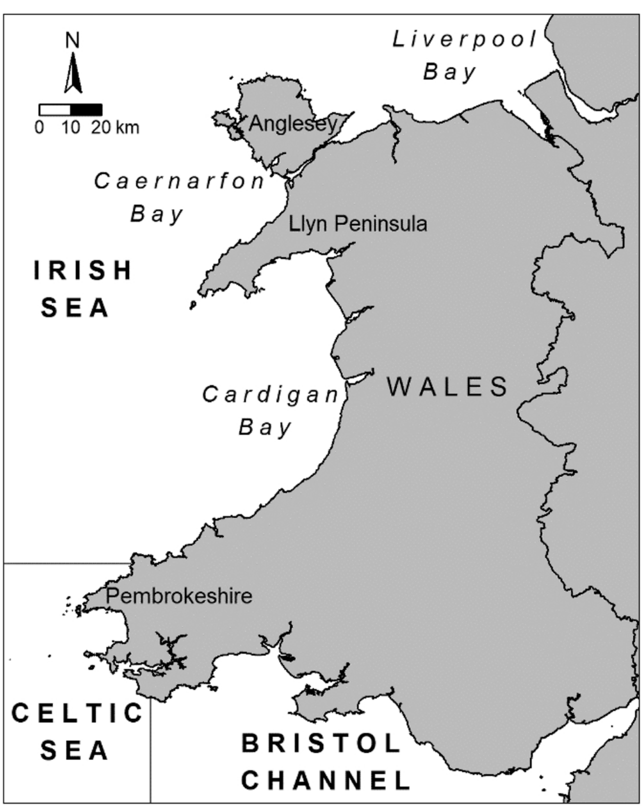

Fig. 1. Map of Wales showing ICES regional seas and locations referred to in the text and Table 1.

2.3. Data collection and analysis

All observations on bycatch took place in the context of time and space constraints of a working commercial vessel during their normal operations and during data collection for other research. When pots were hauled, all fish were identified to species level, with the exception of sea scorpions (Cottidae, *Myoxocephalus scorpius* & *Taurulus bubalis*; both UK species confirmed in our study and aggregated as 'sea scorpions' herein), and some individuals of taxa that were confirmed to species on other occasions: rockling (Gaidropsaridae, *Ciliata mustela* and/or *Gaidropsarus vulgaris*) and wrasse (Labridae, *Labrus bergylta* and/or *Symphodus melops*). Fish were always enumerated and, where possible, measured (total length, TL).

Larger and frequently occurring invertebrates such as spider crab and velvet swimming crab were enumerated where possible, noting that count data likely represent a minimum due to rapid discarding by fishers and high abundances (particularly of spider crab). Carapace length (CL) of spider crab was recorded where possible. For other larger invertebrates (any dimension > ca. 10 cm), presence was usually recorded and sometimes enumerated; whelk *Buccinum undatum* and hermit crab *Pagurus bernhardus* (occupying *B. undatum* shells) could often not be reliably distinguished when in pots being rapidly processed. Smaller invertebrates were not systematically recorded. The fate of bycatch (either discarded, or retained for bait, sale or consumption), was also recorded for most fish and larger invertebrates. In addition to direct observations, we also opportunistically noted fishers' ecological knowledge (FEK) on bycatch species.

Bycatch per unit effort (BPUE), equating to total number of individuals/total number of pots, was calculated for fish (all species pooled), fish species with larger sample sizes (i.e., of >200 and the two abundant invertebrates that were usually enumerated (spider crab, velvet swimming crab). Data normality and homoscedasticity were tested by a Shapiro-Wilk and *F* test respectively. The non-parametric Kruskal–Wallis (K-W) test was subsequently used to examine spatial (i. e., between the regions of north, mid, southwest and south Wales; Table 1) and seasonal trends in the BPUE of species, with post-hoc Wilcoxon rank sum test for pairwise comparisons. Regional comparisons were made separately for the two seasons with most data (i.e., summer and autumn). Data analysis and visualisation was performed in R (R core team, 2022).

2.4. *Commercially important and Endangered, threatened and protected (ETP) species*

'Commercially important' fish and shellfish species are defined here as those which are either a UK quota species (https://www.gov.uk/government/publications/fishing-quota-allocations-for-2021-for-england-and-the-uk), or have other significant commercial fishery management measures in place (European sea bass *Dicentrarchus labrax* https://www.gov.uk/government/publications/bass-industry-guidance-2022). Species were classified as being Endangered, threatened and protected (ETP) if they are listed on one or more of the following: the IUCN *Red List of Threatened Species* ('IUCN' hereafter) as Threatened (i.e. Critically Endangered, Endangered or Vulnerable); Annex II of the EC Habitats Directive (occurring in the UK and for which at least one UK Special Area of Conservation exists; 'Annex II'); the Wildlife and Countryside Act 1981 (as amended)('W&CA'); the OSPAR List of Threatened and/or Declining Species & Habitats ('OSPAR'); and Section 7 of the Environment (Wales) Act 2016 (species of principal importance for the purpose of maintaining and enhancing biodiversity in relation to Wales; 'Section 7′). Common and widespread commercially important fish species also occurring on conservation listings (e.g., cod on Section 7) are not considered as such further here.

3. Results

3.1. *Sampling*

A total of 10,741 pot hauls were observed on a total of 83 day trips with 11 fishers over four years (May 2019-August 2022). Sampling was conducted around the coast of Wales but performed most frequently in the north and southwest (43.9% and 30.8% of total pot hauls, respectively) followed by south (20.4%) and mid Wales (4.9%). Sampling was mainly in the summer (44.6% of total pot hauls) and autumn (36.8%), with less sampling in spring (5.3%) and winter (3.3%), broadly reflecting fishing effort (Pantin et al., 2015b). Sampling was conducted in all four seasons for three fishers: two in the north (Liverpool Bay and north Llŷn peninsula), and one in the southwest (Table 1).

3.2. *Taxonomic composition and abundance*

For fish, a total of 1529 individuals were recorded. These belonged to 30 species, comprising two elasmobranchs (Carcharhiniformes: Scyliorhinidae (catsharks) bullhuss *Scyliorhinus stellaris* (also known as nursehound) and smallspotted catshark *S. canicula*) and 28 teleosts. Teleost species were mostly Perciformes (10 species), Gadiformes (8 species), and Pleuronectiformes (6 species) (Supplementary Information). Nearly 90% of individual fish abundance was made up of just six taxa, termed 'core fish' hereafter (Table 2). The two catsharks were the most abundant fish (51.8% of all fish recorded), although *Scyliorhinus stellaris* was around twice as abundant (33.4%) as *S. canicula* (18.4%) and the most important teleost, ballan wrasse *Labrus bergylta* (16.0%); together, these three species comprised over two-thirds of all fish (67.8%). Sea scorpions (*Myoxocephalus scorpius* & *Taurulus bubalis* combined, 7.9%), three-bearded rockling (*Gaidropsarus vulgaris*, 5.2%) and conger eel (*Conger conger,* 5.1%) bought the total to 85.9%. Most fish species (18 spp.; 60%) were rarely observed (each comprising <1% of total fish abundance), with nearly a third of species (9 spp., 30%) only being recorded as a single individual (Supplementary Information Table 1).

Of the larger invertebrates, most taxonomic richness was contributed by Crustacea (all decapods, 7 species), with Echinodermata (4 taxa), and Mollusca (2 cephalopods, 1 bivalve, 1 gastropod) also contributing (Table 3). Two decapod crustacean species (spider crab *Maja brachydactyla* and velvet swimming crab dominated larger invertebrate abundance (see separate text below and Table 4). Mean carapace length (CL) of spider crab was 122 mm for both females (SD±18, range 48–170, $N = 412$) and males (SD ±15 mm, range 39–230, $N = 1078$). Common whelk *Buccinum undatum* and/or hermit crab *Pagurus bernhardus* frequently occurred, but in small numbers (typically 1–5 per pot when present); other taxa occurred only rarely (Table 3).

3.3. *Seasonal variation*

For fish (all species combined), BPUE peaked in the autumn and was lowest in spring (Fig. 2a). Overall, there was a significant difference in BPUE between seasons (K-W chi-squared = 30.66, df = 3, $p < 0.001$), with all pairwise comparisons significant except summer-winter (Fig. 2a). Catshark *Scyliorhinus stellaris* BPUE also peaked in the autumn and was lowest in spring and winter. A significant seasonal difference (K-W chi-squared = 14.52, df = 3, p-value < 0.01) was due to higher BPUE in autumn compared to spring and summer, and summer compared to spring (Fig. 2b). There was no significant difference in BPUE by season for the catshark *S. canicula* (K-W chi-squared = 0.22, df = 3, p-value = 0.973). For ballan wrasse *L. bergylta* there was an overall significant difference between seasons (K-W chi-squared = 15.7, df = 3, p-value = 0.0013), with pairwise significant differences for all combinations except summer-autumn and spring-winter (Fig. 2c).

Spider crab *M. brachydactyla* occurred in all seasons (Table 4). BPUE (all sites pooled) peaked in summer (June) and was lowest in winter to early spring (December-March) (Fig. 3**a**); the difference between seasons was significant (K-W chi-squared = 18.661, df = 3, $p < 0.001$), with significant pairwise differences between summer-autumn and summer-winter only (Fig. 3**a**). Higher BPUE (>1) of this species was only recorded in summer (all regions) and spring (N Llŷn peninsula 1); the highest BPUE of 3.13 and 3.82 was recorded on the north Llŷn peninsula in June 2022; high BPUE was also recorded in Cardigan Bay (1.93) (Table 4).

Velvet crab *N. puber* occurred in all seasons (Table 4). There was no significant seasonal difference in BPUE (K-W chi-squared = 2.33, df = 3, p-value = 0.51) for all sites pooled, including fishers that used escape gaps from which this species could escape. There was however a significant seasonal difference (K-W chi-squared = 10.83, df = 3, p-value < 0.05) for the single fisher in Pembrokeshire that routinely targeted and retained this species by not using escape gaps, with significantly higher BPUE in autumn compared to spring; and marginal significant differences between spring-autumn and summer-winter (Fig. 3b).

Table 2
Number, relative abundance, length and retention of the six core fish taxa (i.e., together accounting for 86% of individual fish abundance) recorded by observers as bycatch in baited lobster *Homarus gammarus* and crab *Cancer pagurus* pots around the coast of Wales, May 2019-August 2022.

Taxon	Common name	Number recorded	% total fish abundance	Total length (mm) Range (mean±SD)	% of total for which discard/ retention was recorded (DRR)	% of DRR retained (% of this retained as bait)
Elasmobranchii						
Scyliorhinus canicula	Smallspotted catshark	281	18.4	All 300–720 (550 ± 71) ♀360–660 (544 ± 59) ♂510–720 (583 ± 50)	95	44 (100)
Scyliorhinus stellaris	Bullhuss (Nursehound)	510	33.4	♀420–1300 (690 ± 164) ♂420–1220 (688 ± 184)	96	13 (100)
Teleostei						
Conger conger	Conger eel	78	5.1	450–1600 (915 ± 246)	87	50 (88)
Gaidropsarus vulgaris	Three-bearded rockling	79	5.2	280–500 (379 ± 43)	94	59 (92)
Myoxocephalus scorpius & *Taurulus bubalis*	Short-spined & long-spined sea scorpion	121	7.9	30–260 (120 ± 40)	100	0 (-)
Labrus bergylta	Ballan wrasse	245	16.0	150–490 (286 ± 61)	99	90 (98)
Total		1314	86.0			

Table 3
Larger (>~10 cm) invertebrate species recorded by observers as bycatch in baited lobster *Homarus gammarus* and crab *Cancer pagurus* pots around the coast of Wales, May 2019-August 2022. NE: not enumerated.

Taxon	Common name	No. recorded	Occurrence	Notes and retention
Mollusca: Gastropoda				
Buccinum undatum	Common whelk	NE	Widespread & frequent, all seasons	Usually discarded; retained on one occasion for food sale.
Mollusca: Bivalvia				
Pecten maximus	King scallop	2	Llŷn N (Dec)	Discarded
Mollusca: Cephalopoda				
Sepia officinalis	Common cuttlefish	4	Liverpool Bay (Jun/Sep)	Retained for consumption
Eledone cirrhosa	Curled octopus	3	Liverpool Bay, Pembrokeshire (both Nov), Llŷn N (Apr)	Discarded
Crustacea: Decapoda				
Palinurus elephas	Spiny lobster	1	Pembrokeshire (Feb)	134 mm CL, retained for sale
Pagurus bernhardus	Hermit crab	NE	Widespread & frequent, all seasons	Discarded
Maja brachydactyla	Spider crab	See text/Table 4/ Fig. 3 & 4.	Often abundant. See text/Table 4/Fig. 3 & 4.	Often retained for whelk bait; rarely for food sale.
Galathea strigosa	Squat lobster	1	Llŷn SW (Jun)	Ca. 90 mm body length. Discarded
Dromia personata	Sponge crab	8	Llŷn & South; autumn.	Discarded
Necora puber	Velvet swimming crab	See text/Table 4/ Fig. 3 & 4.	Often abundant. See text/Table 4/Fig. 3.	Usually discarded. Two fishers regularly retained for food sale.
Carcinus maenas	Shore crab	NE	Cardigan Bay, Anglesey; summer. Frequent where it occurred (shallow intertidal margin).	Discarded
Echinodermata: Asteroidea				
Crossaster papposus	Sun star	2	Llŷn N (Jan, Jul)	Discarded
Asterias rubens	Common starfish	NE	Liverpool Bay (Jun, Aug-Nov, Jan)	Often common at this location. Discarded
Henricia spp.	Bloody Henry	2	Liverpool Bay (Sep), Llŷn SW2 (Aug)	Discarded
Echinodermata: Echinoidea				
Echinus esculentus	Edible sea urchin	1	Pembrokeshire (Apr)	Discarded

3.4. Spatial variation

The six core fish taxa (*S. stellaris, S. canicula, L. bergylta,* sea scorpions, *G. vulgaris, C. conger*) were widespread, all occurring in each of the four regions. Two fish species were more common in either north Wales (tompot blenny *Parablennius gattorugine*, 97% of recorded individuals) or southern Wales (conger eel *C. conger*, 75% of individuals from south or southwest). Several species of infrequently recorded fish were only recorded in Liverpool Bay (ling *Molva molva*, butterfish *Pholis gunnellus*, dab *Limanda limanda*, plaice *Pleuronectes platessa*, sole *Solea solea*, lemon sole *Microstomus kitt*, rock goby *Gobius paganellus*, snake pipefish *Entelurus aequoreus*).

There were significant differences in BPUE among regions. Fish (all species) BPUE was significantly different between regions, for both summer (K-W chi-squared = 11.89, df = 3, p-value < 0.01) and autumn (K-W chi-squared = 11.05, df = 3, p-value < 0.01; note mid Wales region

Table 4
Bycatch per unit effort (BPUE, number of individuals/number of pots) of spider crab *Maja brachydactyla* (S) and velvet swimming crab *Necora puber* (V) recorded as bycatch in baited lobster *Homarus gammarus* and crab *Cancer pagurus* pots around the coast of Wales, May 2019-August 2022. Values are range (mean ± standard deviation). See Table 1 and Fig. 1 for location information.

Wales region	Area name	Season			
		Spring	Summer	Autumn	Winter
North	Liverpool Bay	S: 0 V: 0.07	S: 0–0.04 (0.01 ± 0.02) V: 0.02–0.56 (0.27 ± 0.19)	S: 0 V: 0.02–1.21 (0.51 ± 0.53)	S: 0 V: 0.74
	Anglesey 1	-	S: 0.19 V: 0.10	S: 0.57 V: 0.19	-
	Anglesey 2	-	S: 0.04 V: 2.72	-	-
	N Llŷn peninsula 1	S: 0.71–1.58 (1.15 ± 0.34) V: 0.06–0.55 (0.20 ± 0.23)	S: 1.04–3.82 (1.93 ± 1.12) V: 0.08–0.15 (0.12 ± 0.04)	S: 0.22–0.83 (0.46 ± 0.25) V: 0.14–0.23 (0.20 ± 0.04)	S: 0–0.12 (0.06 ± 0.08) V: 0.14–0.21 (0.18 ± 0.05)
	N Llŷn peninsula 2	-	-	S: 0.55 V: 0.12	-
	SW Llŷn peninsula 1	-	S: 0.10–1.74 (0.97 ± 0.82) V: 0.04–0.76 (0.32 ± 0.38)	S: 0.14–0.78 (0.29 ± 0.25) V: 0.46–1.58 (0.96 ± 0.52)	-
	SW Llŷn peninsula 2	-	S: 0.25–0.36 (0.30 ± 0.08) V: 0.27–0.32 (0.30 ± 0.04)	-	-
Mid	Cardigan Bay	-	S: 0.57–1.93 (1.25 ± 0.68) V: 0.69–3.12 (1.96 ± 1.22)	-	-
SW	Pembrokeshire	S: 0–0.65 (0.21 ± 0.31) V: 0.28–1.05 (0.64 ± 0.39)	S: 0.17–1.19 (0.79 ± 0.33) V: 0.38–1.18 (0.68 ± 0.28)	S: 0–0.20 (0.08 ± 0.08) V: 1.77–4.74 (2.64 ± 1.42)	S: 0–0.21 (0.10 ± 0.15) V: 1.43–2.14 (1.79 ± 0.50)
South	South 1	-	S: 1.38 V: 0.02	S: 0.01–0.38 (0.10 ± 0.14) V: 0.18–0.79 (0.36 ± 0.22)	-
	South 2	-	S: 0.28 V: 0	S: 0.02–0.10 (0.06 ± 0.03) V: 0.06–0.37 (0.22 ± 0.13)	-

not sampled in autumn). Fish BPUE was significantly lower in the southwest compared to all other regions in summer, with significantly higher fish BPUE in the south (cf. north) in autumn (Table 5).

Bullhuss *Scyliorhinus stellaris* BPUE was also significantly different between regions, for both summer (K-W chi-squared = 11.5, df = 3, p-value < 0.01) and autumn (K-W chi-squared = 16.28, df = 3, p-value < 0.001). In summer, mid Wales was significantly higher than north and southwest, with south also higher than southwest. In autumn BPUE in the south was significantly higher than both north and southwest (Table 5). Ballan wrasse bycatch across regions was significantly different in summer (K-W, Chi-squared = 10.005, df = 3, p-value < 0.05) solely because of greater BPUE in the north compared to the southwest. Autumn differences for this species were also significant (K-W chi-squared = 9.10, df = 2, p-value = 0.02), with BPUE in the south significantly greater than both the north and southwest (Table 5). There was no significant regional difference in *S. canicula* BPUE for either summer or autumn (K-W chi-squared = 0.62, df = 3, p-value = 0.893; KW chi-squared = 2.93, df = 3, p-value = 0.231 respectively).

Small-scale spatial differences in BPUE were notable for *Scyliorhinus stellaris* within location, fishing event, and even within pots. Simultaneous sampling on two separate consecutive days (21 and 22 September 2021) with two fishers fishing from the same south Wales port recorded a BPUE for one fisher (0.18 and 0.4 respectively) that was twice that of the other fisher (0.09 and 0.21) although this was not significant likely due to small sample size (Wilcoxon rank sum test with continuity correction, W= 4, p-value = 0.109). In Cardigan Bay on 17 June 2022, there were no *Scyliorhinus stellaris* in 11 of 14 strings of pots (BPUE of 0), with just two strings containing 89% of individuals for that day (BPUE 0.43). Pots usually contained one *Scyliorhinus stellaris* when present but could contain up to four (all females 730–890 mm TL, Liverpool Bay 9 Oct 2021).

Of the invertebrates, *M. brachydactyla* and *N. puber* were widespread, both occurring in each of the four regions (Table 4). Relatively high spider crab BPUE (i.e. >1) was recorded in all regions. Overall spider crab BPUE was not significantly different between region (K-W chi-squared = 6.54, df = 3, p-value = 0.09), although it was between individual fishers (K-W chi-squared = 41.13, df = 10, p-value < 0.001), not least due to remarkably different BPUE within the north Wales region. In Liverpool Bay spider crab was entirely absent, or only scarce in summer (maximum BPUE 0.04, June 2022), compared to the north Llŷn peninsula (fisher 1) which had BPUE two orders of magnitude greater (maximum BPUE 3.82, June 2022) and where it was present in all seasons. Spider crab BPUE for the three fisher locations for which data for all seasons were available (i.e., north Llŷn peninsula 1, Liverpool Bay and southwest Wales) highlight regional differences (Fig. 4); the pattern in southwest Wales broadly followed that of north Llŷn peninsula 1, but with lower BPUE.

3.5. Retention and discarding of bycatch

In general, fish and invertebrates were alive and vigorous when they came onboard, excepting some of the gadids (particularly pouting *Trisopterus luscus*) which had obvious signs of barotrauma (e.g., exopthalmia 'pop eye' and eversion of oesophagus). Of the six core fish taxa, we recorded a high (87–100%) percentage of whether they were retained or discarded (Table 2). Five of the core taxa were retained to some degree; only sea scorpions were always discarded (Fig. 5). The highest retention of core fish was of ballan wrasse (90% of 242 individuals), with substantial higher proportions also for three-bearded rockling (59% of 72), smallspotted catshark *S. canicula* (44% of 267) and conger eel (50% of 68); 13% of 492 *Scyliorhinus stellaris* were retained (Fig. 5, Table 2). Other frequently occurring fish taxa (i.e., ≥1% total abundance) retained in higher percentages were pouting (62%), cod (44%), corkwing wrasse (56%), ballan/corkwing wrasse not identified to species (100%) and rockling not identified to species (33%) (Supplementary Information Table 1). These data are for the whole

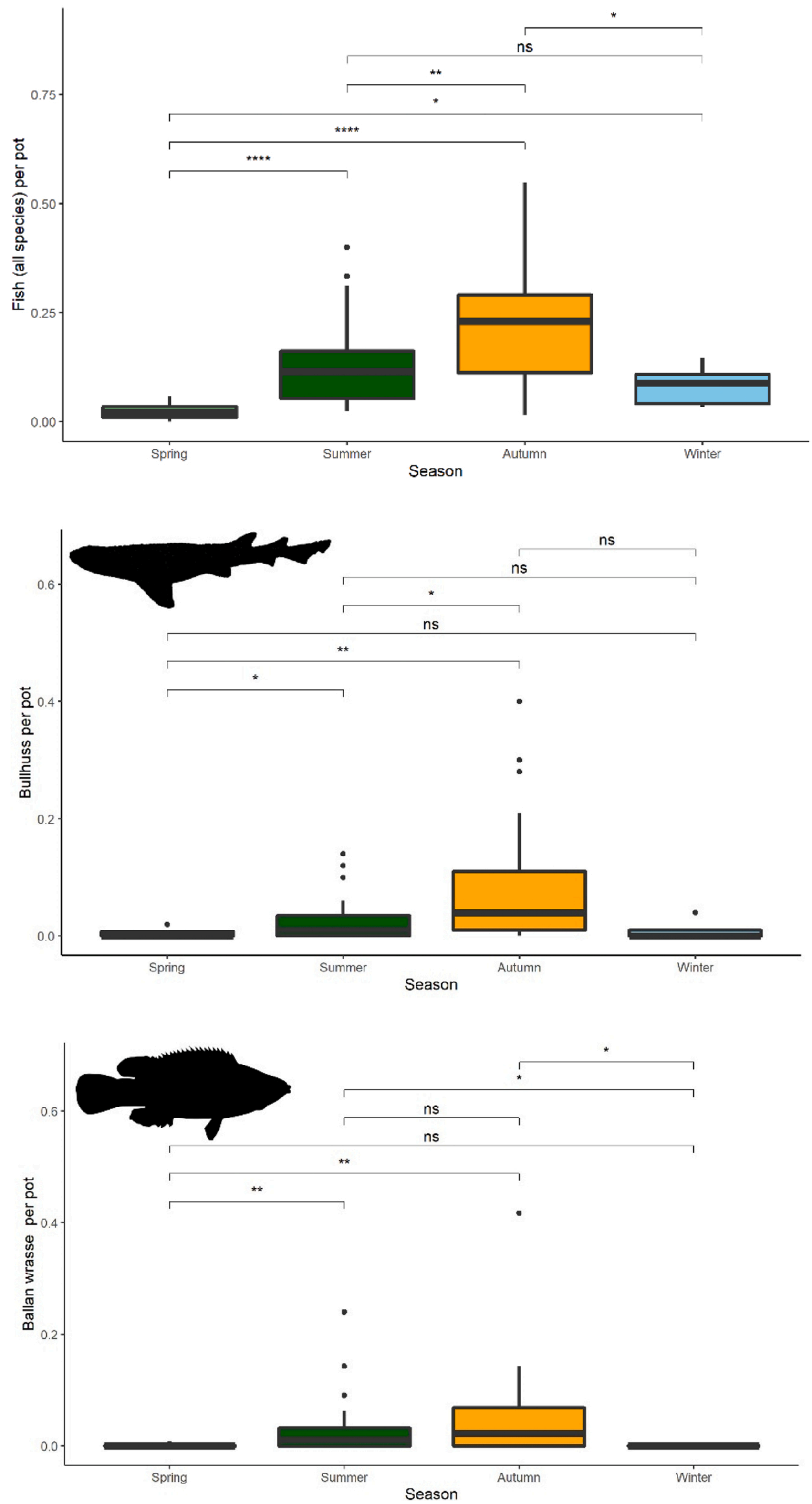

Fig. 2. Seasonal variation in bycatch per unit effort (BPUE; number of individuals/number of pots) for Welsh lobster and crab pot fisheries. A) (top) fish (all species) B) (centre) Bullhuss *Scyliorhinus stellaris* C) (bottom) Ballan wrasse *Labrus bergylta*. Annotations show pairwise comparison Wilcoxon rank sum test significance levels.

study pooled, and retention varied notably by individual fishers: some retained all or nearly all individuals of these taxa, and some retained none or few (pers. obs.). The mean size (± SD) and size range (TL) of the core fish taxa that were both retained and measured was: ballan wrasse 284 ± 60 mm (range 150–490 mm, $n = 173$); *Scyliorhinus stellaris* 679 ± 190 mm (range 430–1100 mm, $n = 57$); *S. canicula* 547 ± 40 mm (range 470–640 mm, $n = 65$) and conger eel 861 ± 185 mm (range 600–1270 mm, $n = 18$).

Where fish species were retained, this was nearly always either for use as bait in the fishers own lobster/crab pots (97–100% of ballan/

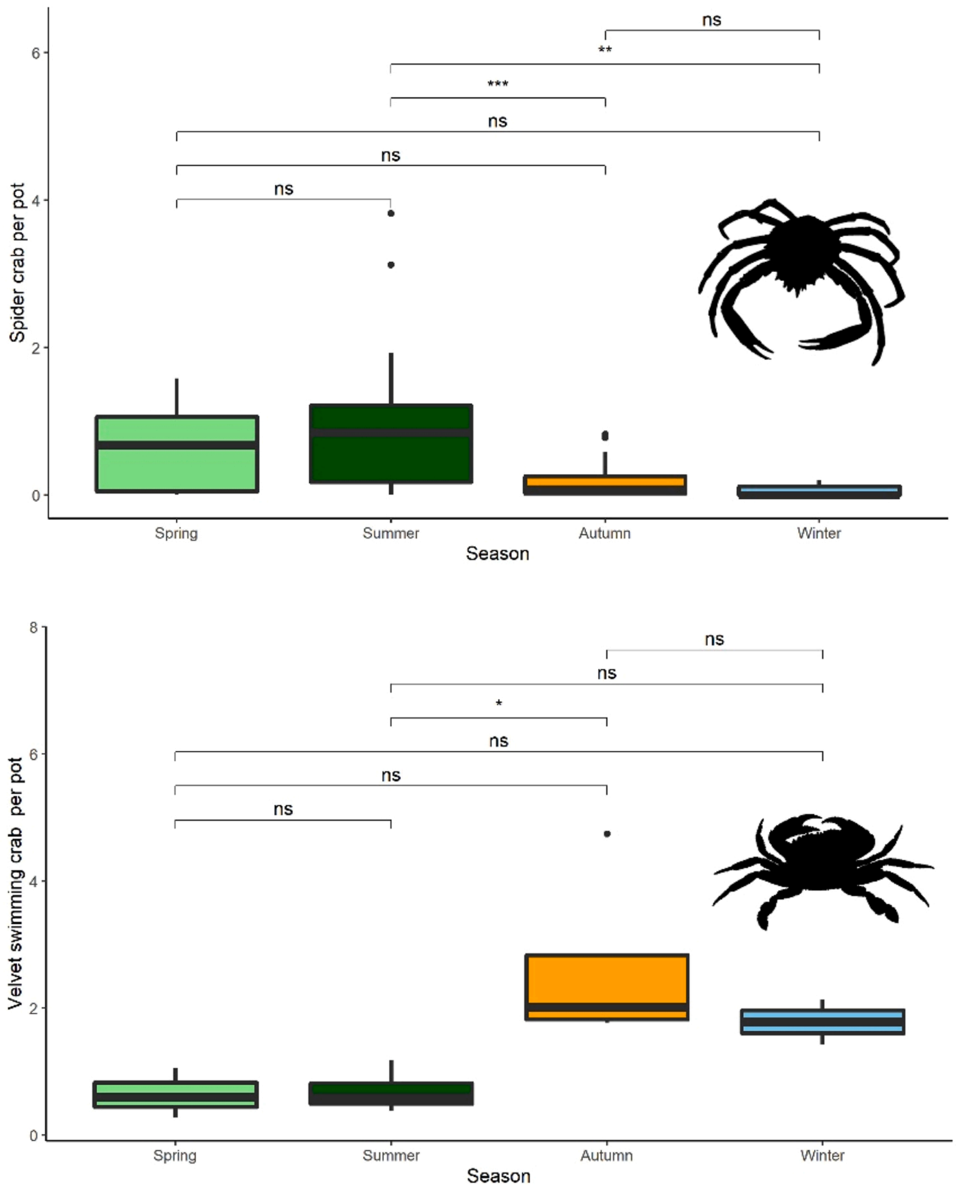

Fig. 3. Seasonal variation in bycatch per unit effort (BPUE; number of individuals/number of pots) for Welsh lobster and crab pot fisheries. A) (top) Spider crab *Maja brachydactyla*, all sites pooled. B) (bottom) Velvet swimming crab *Necora puber*, for the only fisher (southwest Wales; Pembrokeshire in Fig. 1) not using escape gaps that would allow this species to escape. Annotations show pairwise comparison Wilcoxon rank sum test significance levels.

corkwing wrasse, 86% of three-bearded rockling, 81% of conger eel), with catsharks retained either for this purpose or bait for whelk pot fisheries (100% for *S. stellaris* and *S. canicula*)(Table 2). A few individuals of core fish taxa (e.g., conger eel) and commercially important species (e.g. bass, cod) were retained for sale or consumption. Of the fish that were discarded overboard, some taxa (e.g. small gadids and rockling) were sometimes predated by seagulls; sea scorpions, larger fish species (e.g. catshark) and invertebrates were not predated (pers. obs.).

Spider crab were generally either always discarded as a low-value nuisance species or retained in bulk for sale (or for the fishers own use) as whelk pot bait. Larger male spider crab were occasionally selectively retained for sale or consumption. Nearly all fishers discarded velvet swimming crab; only two (in southwest and south Wales) routinely retained these, for sale as food. The single spiny lobster *Palinurus elephas* recorded was legally retained for sale, a few individual cuttlefish were retained for consumption, and on one occasion whelks occurred in sufficient abundance to warrant retention for sale (Table 3).

3.6. Commercially important and ETP species

Commercially important fish species contributed 3.0% of individual fish abundance; seven species were recorded (cod, pollack *Pollachius pollachius*, bass, sole, ling, plaice, lemon sole) the majority (59.6%) of which were cod. ETP species in pots comprised a single spiny lobster *P. elephas* (IUCN Vulnerable; Section 7); the abundant bullhuss *Scyliorhinus stellaris* may be considered ETP based on its global status (IUCN Vulnerable), but not so on its European status (IUCN Near Threatened). No mammals or birds were recorded in pots during all observer work.

3.7. Fishers ecological knowledge

In addition to fish species recorded during observer work, fishers provided anecdotal records of a further three species occurring in pots occasionally during the course of the project. Triggerfish (*Balistes capriscus)*were noted by several fishers across Wales on several occasions in summer and September, with up to 5 individuals in a pot, and a total of

Table 5
Regional differences in bycatch per unit effort (BPUE, number of individuals/ number of pots) of fish taxa recorded as bycatch in baited lobster *Homarus gammarus* and crab *Cancer pagurus* pots around the coast of Wales, May 2019-August 2022, for both summer and autumn. Values are p-values from post-hoc Wilcoxon rank sum test for pairwise comparisons. Significant results ($p < 0.05$) in bold (see text), with region with higher mean indicated in parentheses (N = north, M=mid, S=south).

	Summer			Autumn	
	North	Mid	SW	North	SW
Fish (all species)					
Mid	0.2948	-	-	NA	
SW	**0.0071** ** (N)	**0.0091** ** (M)	-	0.300	-
South	0.2518	0.8000	**0.0364*** (S)	**0.001** **(S)	0.056
Bullhuss					
Mid	**0.0079** ** (M)	-	-	NA	
SW	0.9813	**0.0141** * (M)	-	0.662	-
South	0.0546	0.4000	**0.0394** * (S)	**0.00022** *** (S)	**0.00492** ** (S)
Ballan wrasse					
Mid	0.1574	-	-	NA	
SW	**0.0046** ** (N)	0.8259	-	0.227	-
South	0.6217	0.3743	0.0539	**0.0339** * (S)	**0.0048** ** (S)

around 30 in 'a couple of weeks'. Red mullet (*Mullus surmuletus* one fisher, one occasion, north Wales, autumn); and megrim (*Lepidorhombus whiffiagonis*, one fisher, one occasion, north Wales, winter) were also reported. An individual bluemouth *Helicolenus dactylopterus* (Liverpool Bay, winter of 2020/2021, in around 25 m water depth) reported to us by a fisher with photographic evidence is one of only a handful of UK records (National Biodiversity Atlas, 2022). Fishers sometimes noted that bait type significantly affected bycatch, such as greater catches of *Scyliorhinus stellaris* with farmed salmon waste and more *S. canicula* with scad compared to salted gurnard. Numerous fishers widely reported the abundant spider crab as a nuisance species, which had penetrated into local waters and increased in its distribution and abundance in recent decades (examples in Table 5).(Table 6).

4. Discussion

4.1. Sampling

To our knowledge, our results provide the first peer-reviewed large-scale fishery-dependent study of bycatch in lobster and crab fisheries in the northeast Atlantic. Our sample size and spatial and temporal coverage (10,741 pot hauls and 4.25 years) across three ICES regional seas also exceeds that of the only other published research focusing on pot bycatch regionally, a fishery-independent study in the Irish Sea around the Isle of Man (Öndes et al., 2018; 2489 pots and 1.25 years). Our results support the "scientific evidence objective" of the UK Fisheries Act and will provide hitherto unavailable evidence for industry, regulators, and consumers including sustainable seafood schemes and the first Crabs & Lobsters Fisheries Management Plan (FMP) planned for Welsh waters (Defra, 2022). FMPs are designed to deliver sustainable fisheries, which could in turn help achieve UN Sustainable Development goal 14 (Life Below Water).

Our observer coverage was widespread and substantial yet we acknowledge that, as with all observer programs, our findings may not fully represent bycatch in Welsh lobster and crab pot fisheries. We sampled a total of 11 fishers, on average of 21 days per year, which may represent < 1% of annual lobster pot fishing days in Welsh waters (based on at least 55 fishers fishing an average of 121 days per year; Pantin et al., 2015b). Nevertheless, our results suggest we robustly sampled species composition as we recorded all of the six bycatch taxa recorded in a brief previous field study in Welsh waters, and nearly all of the fish and larger invertebrate species indicated in questionnaire responses of 53 Welsh lobster pot fishers (Pantin et al., 2015a; b). A few less common species, and/or those occurring in seasons or areas where our coverage was low, may have been under-recorded: for example, triggerfish were not directly observed, although FEK suggested its capture is not particularly unusual; observer coverage may also not detect interactions with ETP species (Hatfield et al., 2011). Our results also show that potting may be an efficient way of monitoring some fish species compared to conventional approaches: *Scyliorhinus stellaris*, the most abundant fish in our study and likely an important part of coastal ecosystems, may not be

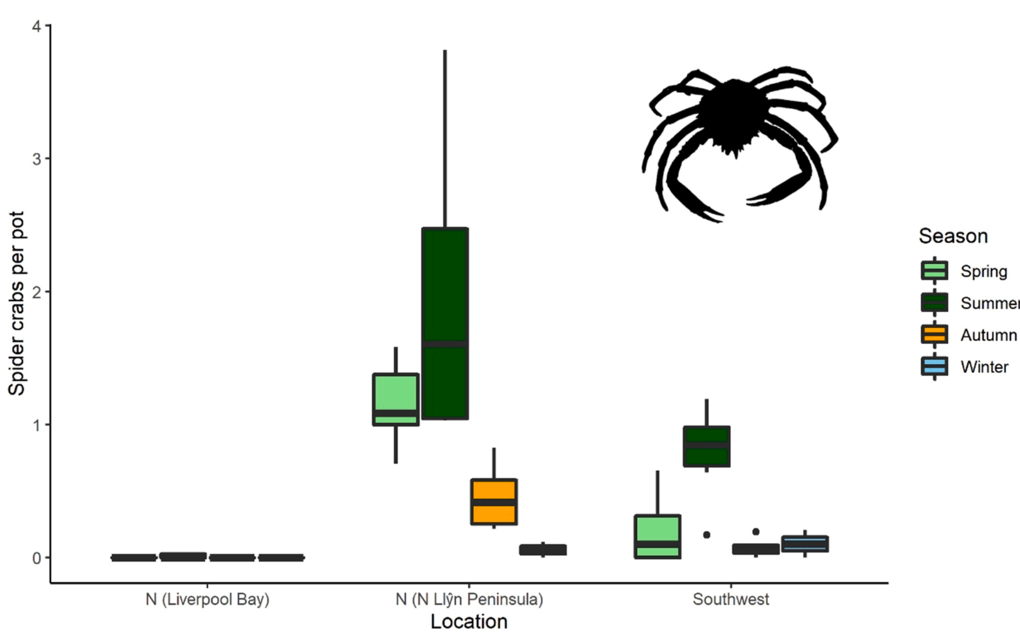

Fig. 4. Spatial and seasonal differences in bycatch per unit effort (BPUE; number of individuals per pot) of spider crab *Maja brachydactyla* in Welsh lobster and crab pot fisheries 2019–2022, for the three locations for which cross-season data were available.

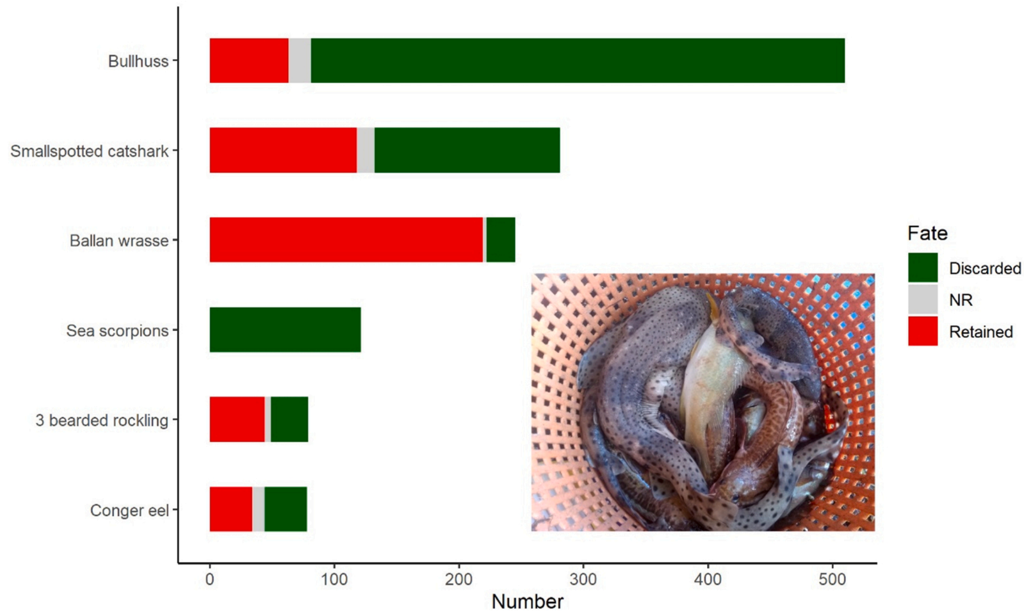

Fig. 5. Number and retention of the six core bycatch fish taxa recorded in Welsh lobster and crab pot fisheries 2019–2022, as either retained (usually for bait) or discarded (returned alive). NR = not recorded. See text for scientific names of taxa.

Table 6
Fishers ecological knowledge of spatial and temporal trends in spider crab *Maja brachydactyla* in Welsh waters.

Fisher location	Fisher's ecological knowledge (FEK)
Llŷn SW 1	*Didn't used to catch them at all when started fishing* [~1988]. *Increased in last 20 years. Peak in abundance June to July* [2021]…*catching females all year round now… large net catch in mid-April in 6 m water depth* [2022]
Llŷn N 1	*Usually come in inshore in May time, but seen huge numbers from the beginning of April this year* [in 2022]… *I have been catching spider crabs inshore and offshore all through the winter. Not in huge numbers, I caught about 25 kg out of 100 pots (5 days soak time) last week* [late January 2023]. *Years gone by, they would disappear in October and not appear until the end of April/May*
Anglesey	*Caught first one ever* [35 years pot fishing experience in this location] *in 2021. Caught a few more in 2022*
Cardigan Bay	*40 years ago* [1970] *my father would have been lucky to catch just one in Cardigan Bay. But now* [2010] *we can literally catch hundreds of them in a single day* (Williams, 2010)

effectively sampled in trawl surveys due to it favouring rough ground (Heessen et al., 2015).

4.2. Spatial and temporal variation

Our findings suggest that there is real spatial variation in bycatch around the coast of Wales, most notably with the abundance of spider crab on the north Llŷn peninsula and in Cardigan Bay, yet its near-absence in Liverpool Bay; there were also hotspots of abundance for fish species, such as south Wales for *Scyliorhinus stellaris* and ballan wrasse. Also of note was the lowest fish (all species) BPUE occurring in southwest Wales; this result is counterintuitive given that this fisher was one of the few with no escape gaps fitted to pots (which would therefore be expected to retain fish); it is possible this is linked to the presence of a large grey seal colony nearby.

On a broader spatial scale, the composition of pot bycatch we found in Welsh waters can be compared to that from the Isle of Man waters of the central Irish Sea (Öndes et al., 2018). Similarities included the abundance of velvet crab *N. puber* and fish species (catshark *S. canicula*, ballan wrasse, conger eel, three-bearded rockling). A remarkable difference was that the most abundant fish (*S. stellaris*) and the sometimes-superabundant spider crab (*M. brachydactyla*) in our study were, respectively, entirely absent and unimportant around the Isle of Man. Conversely, two echinoderms (*Marthasterias glacialis* and *Echinus esculentus*) common around the Isle of Man were respectively absent or only recorded once in our study. Temperature, depth and substrate type drive demersal fish and invertebrate assemblages in the Irish Sea and Bristol Channel (Ellis et al., 2000), and the cooler, more northerly position of the Isle of Man (~70 km north of northernmost Wales, ~ 280 km north of our southernmost area) is likely to be a key factor in bycatch differences. Water temperature differences are also likely to have influenced the differing seasonal patterns found in our study compared to the Isle of Man, such as for *S. canicula* (no seasonal difference in Wales, summer peak in Isle of Man) and *N. puber* (autumn peak in southwest Wales; spring peak in Isle of Man)(Öndes et al., 2018).

Temporal variability in the abundance of bycatch organisms was evident from our study, with the seasonal fish abundance in summer and autumn we recorded likely positively correlated with water temperature. The peak of spider crab abundance in spring and early summer that we found is consistent with previous reports from northern Cardigan Bay and Wales-wide (Walmsley and Pawson, 2007; Pantin et al., 2015b); although no local studies are available, these high abundances are likely associated with reproduction. The higher velvet swimming crab abundance we found in autumn (in southwest Wales, the only location sampled both without escape gaps and cross-seasonally) is likely explained by a lack of spawning activity then, with an absence of ovigerous females reported in southern Wales between September and November (Choy, 1988). Higher abundance outside summer months for this species is also reflected in commercial landings data from southern Wales (Marine Management Organisation, 2022).

Beyond seasonal variation, our findings highlight potentially longer-term significant changes to Welsh inshore ecosystems in recent decades. Our findings of super-abundance of spider crabs in Welsh waters of the Irish Sea (particularly off the north Llŷn peninsula and also in Cardigan Bay), and FEK accounts, strongly support the idea that this species has markedly increased in abundance, northwards range and seasonal occurrence in recent decades. In the 1950s spider crabs were not mentioned as occurring in northern Wales in a Wales-wide government survey of lobster fisheries, nor an anecdotal recollection of lobster potting on the north Llŷn peninsula in July 1953, even though both mention crab *Cancer pagurus* and other bycatch (Simpson, 1958; Owen, 2012). Simpson (1958, p. 23) also noted that spider crab was "very common on the coast of South Wales and is said to have increased over the past 10 to 20 years", although these were considered a nuisance. A commercial spider crab fishery in southern England began in 1979, including in the Bristol Channel, and commercial landings were apparently restricted to this area from 1986 to 1990 (Pawson, 1995; SGCrab, 1995; as *M. squinado*). By the late 1990s spider crab was a dominant component of Bristol Channel demersal assemblages, where seawater temperature was significantly higher than other inshore waters sampled around Wales (Ellis et al., 2000, as *M. squinado*). Further north, spider crabs occurred in sufficient abundance to support fisheries in the south of Cardigan Bay in the mid-1990s, but also occurred up to the SW Llyn peninsula (Gray, 1995), and in 2003 anecdotal accounts of unprecedented abundance in Cardigan Bay were reported in national media (BBC, 2003). Of Welsh fishers catching spider crabs interviewed between 2013 and 2015, 38% believed the species is moving north due to climate change, with an observed increase in abundance in mid Wales (Pantin et al., 2015b). The hypothesis of spider crab expansion as a result of warming seas reported in southern Wales and southern England (SGCrab, 1995; Pantin et al., 2015b) is well supported by an unprecedented increase of 1.66 °C in Irish Sea surface temperature, hindcasted for the period since 1980 (Olbert et al., 2011). Nearly twenty years ago, spider crab (as *M. squinado*) were suggested as a climatically restricted 'southern' species that may spread northwards around Britain which should be monitored (Hiscock et al., 2004). It is remarkable that so few peer-reviewed scientific studies appear to have documented its spread, highlighting the importance of establishing monitoring in areas where they are currently absent or less common (e.g. Liverpool Bay, Isle of Man). The historically recent and seasonally restricted influx of a significant biomass of abundant megabenthos in the form of spider crabs is likely to have implications for coastal ecosystems, and potentially for populations of lobster and edible crab, but these are currently unknown and they warrant further investigation.

4.3. *Bycatch retention*

The presence of a human observer may influence fisher behaviour, and thus underestimation of bycatch retention is a possibility (Benoît and Allard, 2009), although we consider the practices recorded by us likely represent 'real' retention given our positive working relationship with the fishers involved in this study. Regardless, we recorded that 90% of ballan wrasse, and between 44% and 59% of catshark *S. canicula*, conger eel and three-bearded rockling were retained. Ballan wrasse was widespread, occurring in pots of 10 of the 11 fishers (91%) we sampled, likely because this species is found in hard reef substrate and macroalgae habitat favoured by lobsters. Across our whole study, an average trip caught 3.9 ballan wrasse (based on average trip of 129.4 pots hauled (range 19–290, SD±70.3); average ballan wrasse BPUE of 0.03 per pot (range 0–0.42, SD±0.06). Of the fishers who we recorded encountering this species (n = 10), seven (70%) retained it at least once, while three (30%) never retained it. Based on our observations on the 40 trips when ballan wrasse were present in pots, including trips where fishers discarded this species, an average of 5.5 were retained per trip (range 0–23, SD±5.9), estimated as 2.25 kg (mean length of retained fish 284 mm TL, average weight of 413 g based on $W = 0.0127.\ L^{3.1048}$ in Silva et al., 2013). An average of 7.5 ballan wrasse (range 1–23, SD±5.7; 3.1 kg) were retained per trip for those trips where retention occurred (i.e. excluding trips where this species was discarded). Retention practices observed in this study are in contrast to existing industry and seafood sustainability sources which do not specifically mention any fish bycatch or its retention (Marine Conservation Society, 2022a; Seafish, 2022). Further research is needed to quantify removals of fish biomass from bycatch retention across the industry, as this may not currently be accounted for in fisheries or ecosystem management. Retention of fish for bait by fishers appeared to be based on optimal size, durability, scent and practicality; as examples, sea scorpions were always discarded as too small or too spiny to be useful, and large highly active bullhuss and conger eel were often discarded due to the impracticality of dealing with them during hauling (pers. obs.). Welsh pot fishers purchase most of their bait, with retained bycatch generally forming only a small supplementary proportion to help offset costs (Pantin et al., 2015b; pers. obs., various fishers pers. comms.). As noted above, the degree of bycatch retention also varied greatly with individual fishers.

Ballan wrasse were nearly always retained for bait. This species is long-lived and based on an Irish Sea ageing study (Dipper et al., 1977) the mean size of ballan wrasse retained in the present study (284 mm TL) would likely be 9–10 years old; the largest individual we recorded (490 mm TL) would likely be in excess of 25 years old. Ballan wrasse are also protogynous (i.e. maturing as females before maturing as males) with sexual inversion most frequently occurring from the age of 14 years old onwards (Dipper et al., 1977). In addition, ballan wrasse can demonstrate exceptional fine-scale and long-term interannual fidelity to a single rock or group of rocks, with territorial males guarding nests (Villegas-Ríos et al., 2013; Mucientes et al., 2019). As males build and guard nests for eggs, the removal of territorial male wrasse by fishing has been suggested as disrupting social structures and causing reduced egg survival (Darwall et al., 1992). These biological characteristics may therefore make them particularly vulnerable to overexploitation. Monitoring has been recommended for wrasse fisheries, as targeted fisheries for live wrasse have sometimes resulted in CPUE declines and changes in size and age structure (Blanco Gonzalez and de Boer, 2017; Bourlat et al., 2021; Darwall et al., 1992; Halvorsen et al., 2017; Varian et al., 1996). No targeted live wrasse fisheries currently operate in Wales (J. Evans, Welsh Fishermen's Association, pers. comm. 27 Feb 2023).

Also retained as bait was the large catshark *Scyliorhinus stellaris*, the most abundant fish species in pots and one with contrasting conservation assessments. At a global level, the IUCN *Red List* has recently assessed *Scyliorhinus stellaris* as Vulnerable due to a suspected global population reduction of 30–49% within 48 years, largely driven by steep declines, including local extinctions, in the Mediterranean Sea (Finucci et al., 2021). However, the European-level assessment of Near Threatened (Ellis et al., 2015) may be more appropriate to northeast Atlantic waters, given increasing CPUE in the Irish Sea and Bristol Channel (Finucci et al., 2021). Welsh waters may be a *Scyliorhinus stellaris* stronghold: the highest reported abundances of this species and its egg cases around Britain and Ireland have been from the coast of Wales (Ellis et al., 2005; Gordon, 2016). Our findings of abundant *Scyliorhinus stellaris* therefore further support local waters as being of global importance for this species. Given localised depletions elsewhere, large size, restricted habitat, suspected low interconnectivity between populations, and lack of the most basic knowledge of their biology (Finucci et al., 2021), a precautionary approach to sustain existing populations may be warranted. Lobster fishers might be particularly encouraged to maintain healthy populations of *Scyliorhinus stellaris,* as it may be a significant predator of the octopus *Eledone cirrhosa* (Ellis et al., 1996), itself an important predator of lobsters (various fishers pers. comms.; Boyle, 1986).

Ecosystem effects of bycatch retention are unknown. The most common retained species - ballan wrasse, catsharks, and conger eel - are important predators of invertebrates and fish in coastal systems (Dipper et al., 1977; Ellis et al., 1996; O'Sullivan et al., 2004), and as noted above, some may be particularly sensitive to exploitation. Our findings do not allow accurate estimation of annual removals of fish biomass when scaled up across Wales, nor is there population data available on key species (e.g. ballan wrasse) on which to assess potential impact. Nevertheless our findings suggest quantities of fish which may not be negligible are removed annually, with catch concentrated seasonally within the set 'territories' of these static gear fisheries. Although lobster fishers in north Wales have caught and used their own bait, particularly catsharks, for many decades (Pennant, 1810, Simpson 1958, Owen, 2012), the sustainability of this practice cannot be assumed given the expanded and mechanised nature of the modern industry.

In summary, we found that much of the bycatch in Welsh lobster and crab pot fisheries was composed of a small number of species that are common, widespread and not of major commercial or conservation importance (with the possible exception of globally 'Vulnerable' *Scyliorhinus stellaris*, noting European assessment of 'Near Threatened' which may be more applicable to Welsh waters); furthermore, most discarded bycatch was released alive and outwardly appeared to be healthy and undamaged. This broadly aligns with the perception that the fishery has a relatively low bycatch impact compared to some towed gear fisheries that typically affect a wider diversity of species (including commercial species), often with high injury and mortality (Jenkins et al., 2001; Veale et al., 2001; Craven et al., 2012; Öndes et al., 2016). We also found no evidence of mammal or bird entrapment. Our findings also show that bycatch and retention was individually and spatially (and seasonally) variable, with one fisher having remarkably low fish bycatch and some fishers retaining no fish. However, our findings on bycatch retention for bait identifies a source of fish mortality that is currently unacknowledged and unaccounted for by industry and a popular seafood sustainability rating scheme (Seafish, 2022; Marine Conservation Society, 2022a; b). The impacts of this removal, particularly on species which may be vulnerable to over-exploitation (e.g. ballan wrasse) are unknown and warrant both further research and consideration under the objectives of the Fisheries Act regarding non-target species. Options to address bycatch issues could include technological solutions: the use of magnets in fish traps has shown promise in significantly reducing bycatch of benthic sharks while increasing the amount of target species, thereby increasing fishery profitability (Richards et al., 2018).

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CRediT authorship contribution statement

ABMM: Formal analysis, Investigation, Methodology, Project administration, Visualisation, Writing – original draft, Writing – review & editing. **CH**: Investigation, Writing – review & editing. HL: Investigation, Writing – review & editing. **CC, BT, HN:** Investigation. **IDM:** Supervision, Writing – review & editing, Funding acquisition. **NH:** Conceptualisation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2023.106745.

References

Anderson, B.N., Weissman, A.M., Sweezey, B., Mandelman, J., Rudders, D.B., Sulikowski, J.A., 2020. Bycatch in a commercial lobster fishery: effects on two benthic predators, Sea Raven and Longhorn Sculpin. Mar. Coast. Fish. Dyn. Manag. Ecosyst. Sci. 12, 113–123. https://doi.org/10.1002/mcf2.10114.

BBC (2003) Crab invasion under the spotlight. Online news article. 23 June 2003. Available at ⟨http://news.bbc.co.uk/1/hi/wales/mid/3013468.stm⟩ [Downloaded 3/11/2022].

Bellchambers, L.M., Phillips, B.F., Pérez-Ramírez, M., Lozano-Álvarez, E., Ley-Cooper, K., Vega-Velazquez, A., 2014. Addressing environmental considerations for Marine Stewardship Council certification: a case study using lobsters. Mar. Policy 50A, *249–260*. https://doi.org/10.1016/j.marpol.2014.07.006.

Benoît, H.P., Allard, J., 2009. Can the data from at-sea observer surveys be used to make general inferences about catch composition and discards? Can. J. Fish. Aquat. Sci. 66 (12), 2025–2039. https://doi.org/10.1139/F09-116.

Blanco Gonzalez, E., de Boer, F., 2017. The development of the Norwegian wrasse fishery and the use of wrasses as cleaner fish in the salmon aquaculture industry, 2017 Fish. Sci. 83, 661–670. https://doi.org/10.1007/s12562-017-1110-4.

Bloomfield A., Solandt J.-L. (2008) The Marine Conservation Society Basking Shark Watch 20-year report (1987–2006). Marine Conservation Society report.

Boenish, R., Chen, Y., 2020. Re-evaluating Atlantic cod mortality including lobster bycatch: where could we be today? Can. J. Fish. Aquat. Sci. 77 (6), 1049–1058. https://doi.org/10.1139/cjfas-2019-0313.

Botterell, Z.L.R., Penrose, R., Witt, M.J., Godley, B.J., 2020. Long-term insights into marine turtle sightings, strandings and captures around the UK and Ireland (1910–2018). J. Mar. Biol. Assoc. U. Kingd. 1–9. https://doi.org/10.1017/S0025315420000843.

Bourlat, S.J., Faust, E., Wennhage, H., Wikström, A., Rigby, K., Vigo, M., Kraly, P., Selander, E., André, C., 2021. Wrasse fishery on the Swedish West Coast: towards ecosystem-based management. ICES J. Mar. Sci. 78, 1386–1397. https://doi.org/10.1093/icesjms/fsaa249.

Boyle, P.R., 1986. A descriptive ecology of *Eledone cirrhosa* (Mollusca: Cephalopoda) in Scottish Waters. J. Mar. Biol. Assoc. U. Kingd. 66 (4), 855–865. https://doi.org/10.1017/S0025315400048487.

Chen Y., Runnebaums J. (2014) A preliminary study for Improving survivability of cusk bycatch in the Gulf of Maine lobster trap. Final report prepared for NOAA. Available at: ⟨https://apps-nefsc.fisheries.noaa.gov/rcb/publications/reports/EE1333F12SE2038.pdf⟩ [Downloaded 3rd August 2022].

Choy, S., 1988. Reproductive biology of *Liocarcinus puber* and *L. holsatus* (Decapoda, Brachyura, Portunidae) from the Gower Peninsula, South Wales. Mar. Ecol. 9, 227–241. https://doi.org/10.1111/j.1439-0485.1988.tb00330.x.

Craven, H.R., Brand, A.R., Stewart, B.D., 2012. Patterns of impacts of fish bycatch in a scallop dredge fishery. Aquat. Conserv.: Mar. Freshw. Ecosyst. 23 (1), 152–170. https://doi.org/10.1002/aqc.2289.

Cruz, M.J., Machete, M., Menezes, G., Rogan, E., Silva, M.A., 2018. Estimating common dolphin bycatch in the pole-and-line tuna fishery in the Azores. PeerJ 6, e4285. https://doi.org/10.7717/peerj.4285.

Darwall, W.R.T., Costello, M.J., Donnelly, R., Lysaght, S., 1992. Implications of life-history strategies for a new wrasse fishery. J. Fish. Biol. 41, 111–123. https://doi.org/10.1111/j.1095-8649.1992.tb03873.x.

Davies, R.W.D., Cripps, S.J., Nickson, A., Porter, G., 2009. Defining and estimating global marine fisheries bycatch. Mar. Policy 33, 661–672. https://doi.org/10.1016/j.marpol.2009.01.003.

Defra (2022) Consultation on the draft Joint Fisheries Statement. Available at ⟨https://consult.defra.gov.uk/sustainability-devolution-and-legislation-team/jfs/supporting_documents/Consultation%20draft%20of%20the%20Joint%20Fisheries%20Statement.pdf⟩ [Accessed 4th November 2022].

Dipper, F.A., Bridges, C.R., Menz, A., 1977. Age, growth and feeding in the ballan wrasse *Labrus bergylta* Ascanius 1767. J. Fish. Biol. 11, 105–120. https://doi.org/10.1111/j.1095-8649.1977.tb04103.x.

Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M., Harrison, L.R., Carlson, J.K., Davidson, L.N.K., Fordham, S.V., Francis, M.P., Pollock, C.M., Simpfendorfer, C.A., Burgess, G.H., Carpenter, K.E., Compagno, L.J.V., Ebert, D.A., Gibson, C., Heupel, M.R., Livingstone, S.R., Sanciangco, J.C., Stevens, J.D., Valenti, S., White, W.T., 2014. Extinction risk and conservation of the world's sharks and rays. eLife 3, e00590. https://doi.org/10.7554/eLife.00590.

Edwards E. (1979) The Edible Crab and Its Fishery in British Waters. Fishing News Book Ltd, Farnham Surrey, England.

Ellis J., Serena F., Mancusi C., Haka F., Morey G., Guallart J., Schembri T. (2015) *Scyliorhinus stellaris* (Europe assessment). *The IUCN Red List of Threatened Species* 2015: e.T161484A48923567. Accessed on 19 December 2022.

Ellis, J.R., Cruz-Martínez, A., Rackham, B., Rogers, S.I., 2005. The distribution of chondrichthyan fishes around the british isles and implications for conservation. J. Northwest Atl. Fish. Sci. 35, 195–213. https://doi.org/10.2960/J.v35.m485.

Ewins, P.J., 1988. An analysis of ringing recoveries of Black Guillemots *Cepphus grylle* in Britain and Ireland. Ringing Migr. 9, 95–102.

Ferter, K., Weltersbach, M.S., Humborstad, O.-B., Fjelldal, P.G., Sambraus, F., Strehlow, H.V., Vølstad, J.H., 2015. Dive to survive: effects of capture depth on barotrauma and post-release survival of Atlantic cod (*Gadus morhua*) in recreational fisheries. ICES J. Mar. Sci. 72, 2467–2481.

Finucci B., Derrick D., Pacoureau N. (2021) Scyliorhinus stellaris. The IUCN Red List of Threatened Species 2021: e.T161484A124493465. ⟨https://dx.doi.org/10.2305/IUCN.UK.2021–2.RLTS.T161484A124493465.en⟩. Accessed on 27 October 2022.

Galbraith, H., Russell, S., Furness, R.W., 1981. Movements and mortality of Isle of May shags as shown by ringing recoveries. Ringing Migr. 3 (3), 181–189. https://doi.org/10.1080/03078698.1981.9673777.

Gordon C. (2016) The Great Eggcase Hunt: celebrating 100,000 records. Shark Trust web document. Available at ⟨https://www.researchgate.net/publication/311582231_The_Great_Eggcase_Hunt_celebrating_100000_records⟩ [Accessed 27/10/2022].

Gray, C.A., Kennelly, S.J., 2018. Bycatches of endangered, threatened and protected species in marine fisheries. Rev. Fish. Biol. Fish. 28, 521–541. https://doi.org/10.1007/s11160-018-9520-7.

Gray M.J. (1995) The coastal fisheries of England and Wales, Part III: A review of their status 1992–1994. MAFF Fisheries Research Technical Report No. 100. Directorate of Fisheries Research, Lowestoft, 1995.

Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. By-catch: problems and solutions. Mar. Pollut. Bull. 41, 204–219. https://doi.org/10.1016/S0025-326X(00)00111-9.

Halvorsen, K.T., Larsen, T., Sørdalen, T.K., Vøllestad, L.A., Knutsen, H., Olsen, E.M., 2017. Impact of harvesting cleaner fish for salmonid aquaculture assessed from replicated coastal marine protected areas. Mar. Biol. Res. 13 (4), 359–369. https://doi.org/10.1080/17451000.2016.1262042.

Hatfield, B.B., Ames, J.A., Estes, J.A., Tinker, M.T., Johnson, A.B., Staedler, M.M., Harris, M.D., 2011. Sea otter mortality in fish and shellfish traps: estimating potential impacts and exploring possible solutions. Endanger. Species Res. 13, 219–229. https://doi.org/10.3354/esr00327.

Heessen H.J.L., Ellis J.R., Daan N. (2015) Fish Atlas of the Celtic Sea, North Sea and Baltic Sea based on international research-vessel surveys. Wageningen Academic Publishers.

Hiscock, K., Southward, A., Tittley, I., Hawkins, S., 2004. Effects of changing temperature on benthic marine life in Britain and Ireland. Aquat. Conserv.: Mar. Freshw. Ecosyst. 14, 333–362. https://doi.org/10.1002/aqc.628.

Jefferies, D.J., 1989. Further records of fyke net and creel deaths in British otters (*Lutra lutra*) with a discussion on the use of guards. *Otters*. J. Otter Trust 2 (3), 13–20.

Jefferies, D.J., 1993. Otter mortalities due to commercial fishing 1975-1992. In: Morris, P.A. (Ed.), Proceedings of the National Otter Conference Cambridge September 1992. The Mammal Society, Bristol, pp. 25–29, 48 pp.

Jefferies D.J., Green J., Green R. (1984) Commercial fish traps and crustacean traps: serious cause of otter *Lutra lutra* (L.) mortality in Britain and Europe. The Vincent Wildlife Trust, London, 22 pp.

Jenkins, S.R., Beukers-Stewart, B.D., Brand, A.R., 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. Mar. Ecol. Prog. Ser. 215, 297–301. https://doi.org/10.3354/meps215297.

Kennelly, S.J., 1995. The issue of bycatch in Australia's demersal trawl fisheries. Rev. Fish. Biol. Fish. 5, 213–234.

Kruuk, H., Conroy, J.W.H., 1991. Mortality of Otters (*Lutra lutra*) in Shetland. J. Appl. Ecol. 28 (1), 83–94. ⟨http://www.jstor.com/stable/2404115⟩.

Lamb S. (2011) Orkney Sustainable Fisheries: 2010/2011 Project Review. Summary of results and findings of the Orkney shellfish research study 2010/11.

Landa, A., Guidos, S., 2020. Bycatch in local fishery disrupts natural reestablishment of Eurasian otter in western Norway. Conserv. Sci. Pract., e208 https://doi.org/10.1111/csp2.208.

Leaper, R., MacLennan, E., Brownlow, A., Calderan, S., Dyke, K., Evans, P.G.H., Hartny-Mills, L., Jarvis, D., McWhinnie, L., Philp, A., Read, F.L., Robinson, K.P., Ryan, C., 2022. Estimates of humpback and minke whale entanglements in the Scottish static pot (creel) fishery. Endanger. Species Res. 49, 217–232. https://doi.org/10.3354/esr01214.

Marine Conservation Society (2022a) Good Fish Guide. Sustainability rating. European lobster *Homarus gammarus*. Wales (Irish Sea): Welsh waters. Available at ⟨https://www.mcsuk.org/goodfishguide/ratings/wild-capture/465/⟩ [Downloaded 1st August 2022].

Marine Conservation Society (2022b) Good Fish Guide. Sustainability rating. Brown crab *Cancer pagurus*. Wales (Irish Sea): Welsh waters. Available at ⟨https://www.mcsuk.org/goodfishguide/ratings/wild-capture/1046/⟩ [Downloaded 1st August 2022].

Marine Management Organisation (2022) 2021 UK and foreign vessels landings by UK port and UK vessel landings abroad: provisional data. Available at: ⟨https://www.gov.uk/government/publications/uk-and-foreign-vessels-landings-by-uk-port-and-uk-vessel-landings-abroad-provisional-data⟩ [Downloaded 18th October 2022].

Marine Stewardship Council (2022) The MSC Fisheries Standard. Web page. Available at ⟨https://www.msc.org/standards-and-certification/fisheries-standard⟩ [Downloaded 29th July 2022].

Miller, K.I., Nadheeh, I., Jauharee, A.R., Anderson, R.C., Adam, M.S., 2017. Bycatch in the Maldivian pole-and-line tuna fishery. PLoS ONE 12 (5), e0177391. https://doi.org/10.1371/journal.pone.0177391.

Mucientes, G., Irisarri, J., Villegas-Ríos, D., 2019. Interannual fine-scale site fidelity of male ballan wrasse *Labrus bergylta* revealed by photo-identification and tagging. J. Fish. Biol. 95, 1151–1155. https://doi.org/10.1111/jfb.14111MUCIENTESETAL.1155FISH.

National Biodiversity Atlas (2022) Helicolenus dactylopterus (Delaroche, 1809) Blue-mouth. ⟨https://species.nbnatlas.org/species/NBNSYS0000182646⟩. Accessed 6th December 2022.

Northridge S., Cargill A., Coram A., Mandleberg L., Calderan S., Reid B. (2010) Entanglement of minke whales in Scottish waters; an investigation into occurrence, causes and mitigation. University of St. Andrew's Sea Mammal Research Unit Final Report to Scottish Government CR/2007/49. Available at ⟨http://www.smru.st-andrews.ac.uk/files/2015/10/347.pdf⟩ [Downloaded 3rd August 2022].

Öndes, F., Kaiser, M.J., Murray, L.G., 2016. Quantification of the indirect effects of scallop dredge fisheries on a brown crab fishery. Mar. Environ. Res. 119, 136–143. https://doi.org/10.1016/j.marenvres.2016.05.020.

Öndes, F., Kaiser, M.J., Murray, L.G., 2018. Fish and invertebrate by-catch in the crab pot fishery in the Isle of Man, Irish Sea. J. Mar. Biol. Assoc. U. Kingd. 98 (8), 2099–2111.

O'Sullivan, S., Moriarty, C., Davenport, J., 2004. Analysis of the stomach contents of the European conger eel *Conger conger* in Irish waters. J. Mar. Biol. Assoc. U. Kingd. 84 (4), 823–826. https://doi.org/10.1017/S0025315404010008h.

Owen, B. (2012) Nefyn, Wales: Recollections from America. Web article. Available at ⟨http://www.nefyn.com/Stories/NefynLobsterAndMackerelFishing.aspx⟩ [Downloaded 2nd August 2022].

Pantin J.R., Murray L.G., Cambiè G., Le Vay L., Kaiser M.J. (2015a) Escape Gap Study in Cardigan Bay: consequences of using lobster escape gaps. A Preliminary Report. Fisheries & Conservation report No. 44, Bangor University. 43 pp.

Pantin J.R., Murray L.G., Le Vay L., Kaiser M.J. (2015b) The Inshore Fisheries of Wales: a study based on fishers' ecological knowledge. Fisheries & Conservation Science Report No. 42, Bangor University. 60pp.

Pawson M. (ed.)(1995) Biogeographical identification of English Channel fish and shellfish stocks. Fisheries Research Technical Report 99. Ministry of Agriculture, Fisheries and Food Directorate of Fisheries Research.

Pennant T. (1810) Tours in Wales. Volume II. Available at ⟨https://www.google.co.uk/books/edition/Tours_in_Wales/toIPAAAAYAAJ?hl=en&gbpv=1⟩ Accessed 19th December 2022.

Pillans, R.D., Fry, G.C., Carlin, G.D., Patterson, T.A., 2022. Bycatch of a Critically Endangered Shark *Glyphis glyphis* in a Crab Pot Fishery: Implications for Management. Front. Mar. Sci. 9, 787634 https://doi.org/10.3389/fmars.2022.787634.

R core team (2022) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL ⟨https://www.R-project.org/⟩.

Richards, R.J., Raoult, V., Powter, D.M., Gaston, T.F., 2018. Permanent magnets reduce bycatch of benthic sharks in an ocean trap fishery. Fish. Res. 208, 16–21. https://doi.org/10.1016/j.fishres.2018.07.006.

Roosenburg, W.M., Green, J.P., 2000. Impact of a bycatch reduction device on diamondback terrapin and blue crab capture in crab pots. Ecol. Appl. 10, 882–889. https://doi.org/10.2307/2641052.

Rya C., Leaper R., Evans P.G.H., Dyke K., Robinson K.P., Haskins G.N., Calderan S., van Geel C.F., Harries O., Froud K., Brownlow A., Jack A. (2016) *Entanglement: an emerging threat to humpback whales in Scottish waters*. International Whaling Commission.

Seafish (2022) Pots and traps: lobster. Web page. Available at ⟨https://www.seafish.org/responsible-sourcing/fishing-gear-database/gear/pots-and-traps-lobster/⟩. [Downloaded 29th July 2022].

SGCrab, 1995. Report of the study group on the biology and life history of majid crabs. La Coruna, Spain, 20-23 November 1995. ICES Shellfish Comm. CM 1996/K. 1.

Silva J.F., Ellis J.R., Ayers R. (2013) Length-weight relationships of marine fish collected from around the British Isles. Science Series Technical Report, CEFAS, 150: 109 pp.

Sotelo, G., Morán, P., Posada, D., 2008. Genetic identification of the Northeastern Atlantic Spiny Spider Crab as *Maja Brachydactyla*. J. Crustace Biol. 28 (1), 76–81. https://doi.org/10.1651/07-2875R.1.

Stevens, B.G., 2021. The ups and downs of traps: environmental impacts, entanglement, mitigation, and the future of trap fishing for crustaceans and fish. ICES J. Mar. Sci. 78 (2), 584–596. https://doi.org/10.1093/icesjms/fsaa135.

Stevens, J.D., Bonfil, R., Dulvy, N.K., Walker, P.A., 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Sci. 57, 476–494.

Twelves, J., 1983. Otter (*Lutra lutra*) mortalities in lobster creels. J. Zool. 201, 585–588.

UK Government (2020) Fisheries Act 2020. Fisheries objectives. Online legislation. Available at: ⟨https://www.legislation.gov.uk/ukpga/2020/22/section/1/enacted⟩ [accessed 28th February 2023].

United Nations (2022) Sustainable Development Goals ⟨https://sdgs.un.org/goals⟩ [Downloaded 24th October 2022].

Varian, S.J.A., Deady, S., Fives, J.M., 1996. The effect of intensive fishing of wild wrasse populations in Lettercallow Bay, Connemara, Ireland: implications for the future management of the fishery. Wrasse: Biology and Use in Aquaculture. Blackwell Scientific, Oxford, pp. 100–118.

Veale, L., Hill, A., Hawkins, S., Brand, A., 2001. Distribution and damage to the by-catch assemblages of the northern Irish Sea scallop dredge fisheries. J. Mar. Biol. Assoc. U. Kingd. 81 (1), 85–96. https://doi.org/10.1017/S0025315401003435.

Villegas-Ríos, D., Alós, J., March, D., Palmer, M., Mucientes, G., Saborido-Rey, F., 2013. Home range and diel behavior of the ballan wrasse, *Labrus bergylta*, determined by acoustic telemetry. J. Sea Res. 80, 61–71. https://doi.org/10.1016/j.seares.2013.02.009.

Wallace N. , Rae V. (2017) Escape gap project. Northumberland Inshore Fisheries and Conservation Authority. Available at: ⟨https://nifca.gov.uk/wp-content/uploads/2022/02/2016–2017-NIFCA-Escape-Gap-Project.pdf⟩ [Downloaded 24th October 2022].

Walmsley, S.A., Pawson, M.G., 2007. The coastal fisheries of England and Wales, Part V: a review of their status 2005–6. Sci. Ser. Tech. Rep. 83.

WFA CPC (2022) Wales Seafood Industry Dashboard - Economic Value. Web page. Available at ⟨https://walesdashboard.wfa-cpc.wales/⟩ [Downloaded 29th July 2022].

Williams S. (2010) Welsh crab fishermen net Raymond Blanc deal. Online news article. Available at: ⟨https://www.walesonline.co.uk/news/wales-news/welsh-crab-fishermen-net-raymond-1913906⟩ [Accessed 29th October 2022].