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Using angling logbook data to inform fishery management decisions

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ABSTRACT

This paper presents a methodology that uses fishery data collected for the purpose of administering and monitoring harvest quotas in a recreational fishery to give additional insights into effectiveness of various fishing methods, and expected catch rates associated with different licence types. The empirical application is based on the Atlantic salmon (*Salmo salar*) recreational fishery in Ireland but the statistical analysis is easy to replicate and the models are flexible enough to allow different specifications applicable to other fisheries. The output of the analysis facilitates a better understanding of the factors associated with recreational catches, which in turn provides supplementary information to inform the regulation and management of recreational fisheries.

1. Introduction

Fish provide important ecosystem services not only for food but also for habitat stability and regulation. From a cultural perspective fish have a strong historical relationship with humans' economic activity and recreation (AAAS, 1997). At present, fish stocks are subject to manifold anthropogenic stresses such as pollution, invasive species, river fragmentation and habitat loss that are threatening the sustainability of stock resources (Cambray, 2003; Carpenter et al., 2017). At the same time fish stocks are seriously affected by overfishing (i.e. excessive harvest resulting in depleting fish stocks) as one of the main drivers of declining populations (Camp, Larkin, Ahrens, & Lorenzen, 2017). For this reason a sustainable management of a fishery involves constant monitoring of catch rates. This is important for commercial fishing activities, however, recreational angling has also a relevant impact on fish stocks, although it is often overlooked.

Recreational angling has raised interest in economic terms because it represents a source of income for local communities that are frequently located in remote and relatively poor areas (Cookie & Cowx, 2005; Curtis, Breen, O'Reilly, & O'Donoghue, 2017; Lawrence, 2005; Toivonen et al., 2004), as well as its impact on environmental sustainability (Gagne et al., 2017; Ready et al., 2018). It is estimated that 11% of the world population practice fishing as a social and leisure activity (Arlinghaus, Tillner, & Bork, 2015). Therefore, even if the individual impact of one recreational angler is small, the cumulative effect of all anglers becomes extremely important for sustainability. Cooke and Cowx (2006) reported that recreational angling is responsible for about 12% of the total catches worldwide. Zarauz et al. (2015) argue that in the Basque Country recreational landings were found to be higher than expected after a monitoring period, accounting for roughly half of the total harvest. For some popular species, such as Largemouth bass (*Micropterus salmoides*), Rainbow Trout (*Oncorhynchus mykiss*), Sockeye Salmon (*Oncorhynchus nerka*) and Yellow Perch (*Perca flavescens*), recreational landings are estimated to exceed commercial volumes (Lewin, Arlinghaus, & Mehner, 2006). McPhee, Leadbitter, and Skilleter (2002) argue that recreational fishing is not sustainable in the long term without constant monitoring and control. For example, Schroeder and Love (2002) find large differences in fish species density and specimen size in comparable adjacent areas, one of which is subject to recreational fishing and the other a fishery reserve.

Fisheries are complex systems and their dynamics are always subject to a certain degree of uncertainty (Dayton, 1998) plus management failures may be due to poor decisions and inadequate or erroneous scientific information (Maunder et al., 2006). In some cases fish might be overexploited before scientists and managers have the necessary data to realise the decline in populations. Systematic monitoring of recreational angling activity and the volume of fish harvesting is necessary for sustainable management, as there is evidence that overexploited fisheries rarely recover after collapse (Hutchings, 2000). Effective management is fundamental when a fish species shows declining stocks, as the case of salmonids in Ireland. Salmon in Irish waters have been heavily exploited for many years. In an attempt to tackle the situation and assure a viable

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salmon population, commercial salmon fishing was curtailed in the early 2000s and a drift net ban was introduced in 2007. Recreational angling for salmonids is also well regulated, with a licence required for salmon (*Salmo salar*) or sea trout (*Salmo trutta*) fishing, unlike other target species within Ireland, plus anglers are subject to both daily and season bag limits. Anglers must report their catch via logbook returns. The use of such logbooks is quite common in many countries to record data for many fish species and for several angling activities.

The main advantage of a logbook scheme is the possibility to monitor the fishery at a relatively low cost (Pollock, Jones, & Brown, 1995) and there are many practical applications (Kerr, 2007; Mosindy & Duffy, 2007; Prince, Ortiz, & Venizelos, 2002). Logbook returns are often used to estimate catch per unit effort (CPUE) (Anderson & Thompson, 1991; Jansen, Arlinghaus, Als, & Skov, 2013; Stephens & MacCall, 2004) or for assessing anthropogenic pressure on fish stocks (Jankovský, Boukal, Pivnička, & Kubečka, 2011; van der Hammen, de Graaf, & Lyle, 2015). Mosindy and Duffy (2007) contrast creel surveys with data collected with diaries in Ontario (Canada) and find that diaries provide cost-effective results for catch and effort assessment. Several voluntary species-specific diary schemes have been implemented in New Zealand, where these experiences suggest that logbooks represent an efficient sampling programme for data collection (Hartill & Thompson, 2016; Starr, 2010).

In Ireland logbook return data from recreational salmon anglers, in particular river-specific weight data, have been used to develop river scale biological reference points, which are used to set conservation limits above which a harvest fishery is allowed (White et al., 2016). In practice the level of angling harvest in most salmon fisheries is usually well under the allocated total allowable catch. The approach developed by White et al. (2016) is judged to be a significantly improved method of assessing conservation limits and is a major development for the conservation and management of salmon stocks on a river-by-river basis. The empirical analysis in this paper utilises the same logbook return data and provides insight into another aspect of river specific management guidance – the efficacy of various fishing methods. The purpose of the paper is to demonstrate that valuable fishery management information can be extracted from the logbook data even in the absence of information on angler effort. The modelling results can be used to implement a data-driven management regime, e.g. revising regulations related to various fishing methods to adjust expected catch.

A parametric approach is proposed to analyse logbook data and identify the extent to which angling-specific variables are associated with successful catch. Unlike previous research, we do not estimate CPUE but focus on factors associated with the probability of a catch, as our dataset contains no information on fishing effort. The primary objective of the analysis is to provide fishery managers information on the most successful methods of fishing controlling for differences across fisheries and anglers. This information may aid fishery management decisions when the sustainability of fish stocks are threatened. A secondary analysis is undertaken with respect to licence types, which vary by duration and geographical location. The type of licence purchased will reflect an angler's needs, e.g. 1-day versus season long licence. The logbook returns data enable the assessment of the ex-post expected value for money of licence types, i.e. expected catch per licence unit cost, which is information that should be useful for the administration of the licensing system. This contrasts with the standard approach to the economic valuation of angling, which usually entails estimating an angling demand function and calculating consumer (angler) surplus (Curtis, 2002; Englin, Lambert, & Shaw, 1997; Grilli, Curtis, Hynes, & O'Reilly, 2018; Hynes, Gaeven, & O'Reilly, 2017; Morey & Waldman, 1998).

The remainder of the paper is organised as follows. Section 2 briefly reviews the state of salmon angling in Ireland. Section 3 then presents the methodology used in the analysis. Section 4 presents the results. Section 5 then discusses how the information generated from the modelling approach used is useful to in terms of regulation and management of recreational fisheries. It also includes a discussion of the policy implications related to the model findings. Finally, Section 6 offers some conclusions.

2. Background – salmon angling in Ireland

The Atlantic salmon is a native Irish fish. The salmon fishing season opens on the majority of Irish rivers on various dates in February, March, April and May. For a small number the start date is January 1st. The majority of rivers close to salmon fishing on September 30th. The bigger fish known as 'Springers' tend to run in the early months of the year and weigh an average of nine pounds (Angling Ireland, 2018). The biggest run of salmon occurs in the summer months although many Irish rivers also have large runs of salmon at the beginning of the autumn. Large-scale commercial salmon fishing ended in Ireland in 2007 with the introduction of a mixed-stock drift net ban. Recreational anglers are now the primary users of Ireland's wild salmon resources. The best salmon rivers are generally located on the western and southern coasts in areas where angling related employment is an important income source in what are often rural locations with limited employment opportunities.

Inland Fisheries Ireland (IFI) has responsibility for salmon fishery management in Ireland. Angler logbook returns are a key source of data on angler catch and combined with other biological data sources, e.g. fish counters, stocks in individual rivers are assessed, conservation limit thresholds established, and where appropriate, total allowable catches assigned. In most fisheries angling harvest is well under the total allowable catch, while individual fishery regulations are updated on an annual basis.[1]

With respect to rod angling, when fishing for salmon and sea trout in Ireland a State licence is required. At present there are several different types of licences that anglers can choose from, differing by time and geographical location:

- Annual, all-districts
- Annual, district-specific (one only of 17 fishery districts/regions)
- Annual, juvenile (below 18 years old), all districts
- 21 day, all-districts
- 1 day, all-districts
- Special licence for the Foyle river[2]
- Other special local licences

A fishing permit or club membership may also be required at some locations. Salmon and sea trout angling is subject to the 'Wild salmon and sea trout tagging scheme' administered by IFI. The principal aims of tagging scheme are to provide accurate nominal catch statistics and stock exploitation, and provide support for management strategies to ensure individual stocks are exploited in a manner consistent with their long-term sustainability. When an angler purchases a licence they also receive a logbook and gill tags. Anglers must attach a gill tag to all salmon and sea trout harvested (the minimum size for a fish to be retained is 40 cm) and record all details of the catch in the logbook. Released fish must also be recorded, not just harvested fish. Information recorded in the logbook includes date and location, length and weight of the fish, the species (salmon or sea trout), fishing method (i.e. type of bait), and whether the fish was released or not. While returning logbooks at the end of the season is mandatory, approximately 30% of logbooks are not returned. The majority of non-returned logbooks are associated with 1-day licences where catches are relatively few due to low effort and possibly angler inexperience, or where no catch is recorded. The logbook return data is consequently confined to anglers with positive catch.

[1] For further information see IFI (2017a, 2017b, 2019) and DCCAE (2018).

[2] The Foyle river represents the boundary between the Republic of Ireland and Northern Ireland. This licence allows anglers to fish from both river banks.

Table 1
Catch rates conditional on positive catch by fishing method, licence type and angler origin for 2016 season.

Conditional average catch per angler for 2016 season				3.08		
Standard deviation				(3.67)		
By fishing method per angler:		Shrimp	Spinners	Worms	Fly	
(one river)						
Conditional average catch		3.81	3.02	2.7	3.22	
Standard deviation		(4.48)	(3.54)	(2.83)	(3.95)	
Frequency (%)		9	30	22	39	
By licence type per angler:	Annual	District	Juvenile	1 day	21 day	Foyle ext.
(one fishing method and one river)						
Conditional average catch	3.30	3.42	2.24	2.22	1.22	2.34
Standard deviation	(4.12)	(3.82)	(2.26)	(2.16)	(0.83)	(2.30)
Frequency (%)	38	40	3	14	1	4
By angler country of origin per angler:	Ireland	N. Ireland	Great Britain	Europe	America	Australasia
(one fishing method and one river)						
Conditional average catch	3.26	2.67	2.65	2.47	2.16	3.00
Standard deviation	(3.95)	(2.40)	(3.37)	(2.08)	(1.99)	(3.39)
Frequency (%)	76.2	8.2	6.5	8.5	0.4	0.2

Source: 2016 IFI logbook returns.

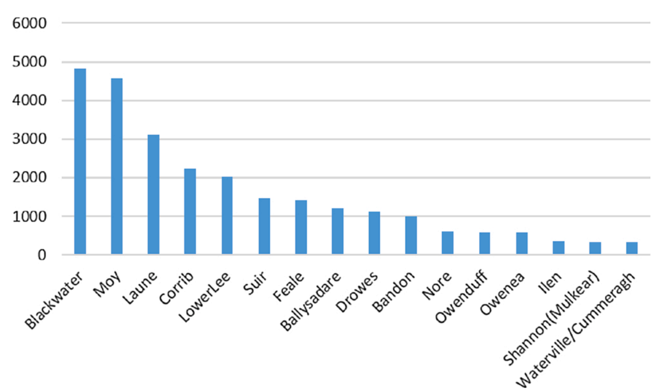


Fig. 1. Most prolific rivers for salmon in Ireland (source: IFI (2017b, Table 10)).

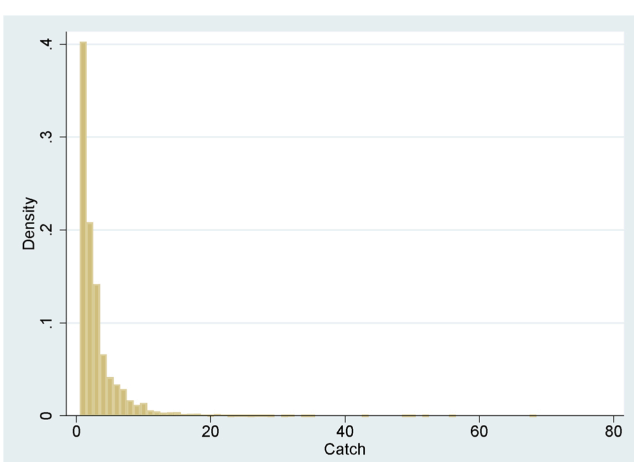


Fig. 2. Histogram: number of salmon caught per angler (by river-method combination).

3. Methods

3.1. Data description

Our analysis relates to logbook returns for the 2016 salmon angling season. The initial dataset had 22,954 observations, each representing a fish caught. We excluded records related to sea trout, totalling 1145 observations, i.e. less than 5% of the total, as our focus is on salmon. Observations with missing data (e.g. unknown fishing method or location) were also excluded. The data was then organised as a panel of anglers by fishing method and by river system such that each row of the panel recorded the number of fish caught by an angler in one river system with a specific fishing method. For example, if an angler caught fish in two rivers with the same method, then his catch is recorded as two rows in the dataset. If an angler caught fish in just one river but using two different fishing methods his catch is also recorded in two rows of the dataset. The final dataset had 6811 observations grouped by 4662 anglers, which is an unbalanced panel of anglers across rivers and methods. Descriptive statistics of the sample are shown in Table 1.

For anglers that did not return logbooks we have no information on the fishing location (i.e. river system) nor the fishing methods used. Also, as the logbook returns are limited to positive catches the sample is truncated at zero and the average catch per angler in Table 1 is conditional on positive catch. The sample annual average catch per angler, conditional on positive catch is 3.08 (3.67) salmon. A histogram of catches is presented in Fig. 2. The maximum number of salmon caught by an angler using a single method in one river was 68 and with an annual bag limit of 10 fish almost all of these fish were released. The average catch across all anglers, including those with zero catch, is lower. To account for the fact that part of the population of anglers do not catch during the season the most common solution is to adopt a statistical model truncated at zero (Hilbe, 2011), which will be described in the next subsection. The most prolific fishing methods per angler in a single river are spinners and fly fishing (39% and 30% of the catch, respectively), followed by worms (22%) and shrimps (9%). Of the 4662 anglers in the dataset, 32% held an annual-all districts licence, 43% held an annual district-only licence, 18% held a 21-day licence, with the remaining 8% holding other licence types. Catch by single fishing method and single river system categorised by licence type and angler country of origin are also reported in Table 1.

3.2. Statistical model

The variable of interest is the number of fish caught by river-fishing method combination, which was illustrated graphically in Fig. 2. The distribution of a count variable such as the number of fish caught covers non-negative integer values only, which is typically modelled by either Poisson or negative binomial (NB) distributions that are defined over non-negative integers. A well recognised shortcoming of the Poisson model in empirical applications is the imposition of equality of mean and variance. This assumption is often violated and many datasets show over-dispersed data, i.e. variance larger than the mean. Overdispersion occurs when a few anglers catch a very larger number of fish compared to the average, boosting the variance of the distribution. This has similar consequences to heteroscedasticity in linear regression models and in non-truncated samples leads to biases in standard error estimates. However, in a truncated sample over-dispersion leads to inconsistent and inflated estimates, therefore corrections are needed for a valid model (Hilbe, 2011). Our sample was truncated at zero as anglers with no catch were not recorded, therefore we adopt a truncated NB model. The NB distribution, which includes an extra parameter to account for overdispersion, is often used as an alternative to the Poisson. The truncated NB model has the following log-likelihood function:

$$\Pr[T = t] = \frac{\Gamma(\alpha^{-1} + t_{\mathrm{irm}})}{\Gamma(\alpha^{-1})\Gamma(t_{\mathrm{irm}} + 1)} (\alpha\mu)^{y} (1 + \alpha\mu)^{-(y+\alpha^{-1})} \left[\frac{1}{1 - (1 + \alpha\mu)^{\alpha^{-1}}}\right] \quad (1)$$

where μ is the rate parameter that is usually parametrised with an exponential function $\mu = \exp(X'\beta)$, α represents the over-dispersion parameter and Γ indicates the gamma function that distributes t_{irm} as a gamma random variable. In the special case in which the α parameter is equal to zero, the NB and Poisson models are the same (Cameron & Trivedi, 1986).

Nominally our dataset is a panel of anglers but estimating a panel regression, such as a fixed effects model, though feasible is not practically useful as policy relevant angler-invariant variables (e.g. licence type, angler country of origin) are dropped during estimation (Baltagi, 2013). While this feature does not occur in random effects models, random effects assume exogeneity of all the regressors (i.e. X) with the model's random individual effects (Mundlak, 1978), which is not a reasonable assumption in this application. Variables such as licence type or angler country of origin are likely to be correlated with the error term. The estimation approach taken here is a least squares dummy variables (LSDV) count model, which is a pooled regression model that provides parameter estimates equivalent to the fixed effects model but additionally includes parameter estimates associated with variables normally dropped from the fixed effects model (Baltagi, 2013). The dropped variables in a regular fixed effects panel framework are usually described as 'time-invariant' but in the context of this panel are observations that do not vary within angler groups. In the current dataset the dropped observations would relate to all anglers with just one observation, i.e. they only catch salmon by one method from one river, and represent 48% of anglers in the dataset. Following the LSDV approach means that the information from these anglers is not lost. However, during estimation it is important to account for the fact that observations from the same angler are related. For instance, more skilled anglers are likely to catch higher numbers of salmon irrespective of fishing methods or the river compared to less skilful anglers. Consequently, to allow for angler heterogeneity during estimation we estimate a weighted regression model, where the inverse of the number of observations per angler is used as a weight. We calculated the variance inflation factor coefficient (VIF) to check whether the explanatory variables were collinear. A VIF higher than 10 for one variable is usually an indication that the variable is collinear with another and should be dropped to allow stability in the model (Greene, 2003).

The estimated parameter vector, $\widehat{\beta}$, reflects how the probability of fish caught is associated with the explanatory variables, X, but the parameter values themselves are not of direct policy relevance. To consider the practical implications of the model estimates we calculate predicted mean catch, $\widehat{\mu}$, and conditional predicted mean catch, $\widehat{\mu}_c$, which is conditional on specific values of the independent variables, X_c. For example, the predicted mean catch conditional on fishing method or licence type.

$$\widehat{\mu}_c = \exp(X_c'\widehat{\beta}) \quad (2)$$

Table 2
Results of the econometric models.

	NB	NB w\ interactions
Methods (reference category: shrimp)		
Spinner	− 0.416***	− 0.483***
	(0.0733)	(0.165)
Worms	− 0.282***	− 0.634***
	(0.0772)	(0.184)
Fly fishing	− 0.210***	− 0.446***
	(0.0725)	(0.158)
Fishing licence (reference category: National)		
District	0.136***	0.119**
	(0.0494)	(0.0483)
Juvenile	− 0.535***	− 0.572***
	(0.125)	(0.118)
21 day	− 0.823***	− 0.819***
	(0.0982)	(0.0968)
1 day	− 2.448***	− 2.427***
	(0.415)	(0.417)
Foyle-extended licence	− 0.347**	− 0.358**
	(0.144)	(0.140)
Nationaly (reference category: Ireland)		
Northern Ireland	− 0.0190	− 0.0420
	(0.0833)	(0.0831)
UK	0.397***	0.323***
	(0.126)	(0.123)
Europe	0.282***	0.281***
	(0.0963)	(0.0947)
America	− 0.578	− 0.610
	(0.410)	(0.405)
Australasia	0.752	0.769
	(0.513)	(0.489)
		(0.542)
Constant	0.353***	0.622***
	(0.107)	(0.159)
α	2.612***	2.359***
	(0.272)	(0.227)
Pseudo R-squared	0.029	0.033
AIC	17245.0	17245.9
BIC	17456.6	17710.1
Log-likelihood	− 8591.5	− 8555.0
Observations	6811	6811

Robust standard errors clustered at individual level in parentheses. *p < 0.10, **p < 0.05, ***p < 0.01.

As an additional post-estimation analysis, we show the relative cost of each type of licence based on the expected catch. This is done by calculating the ratio between the expected average catch per licence type and the licence price. This provides a measure of the value of certain licence types based on the expected annual bag, quantified as the licence cost per expected fish caught.

4. Results and discussions

4.1. Econometric models

Table 2 shows results of two regression models. Both models are weighted NB and differ because the first contains only main effects of the coefficients and the second includes also some interaction terms between fishing methods and the river.[3] The average VIF was 1.15 (maximum 3.52), which indicates that multicollinearity is not a serious

[3] The model with interaction terms included a large number of coefficients. For space and legibility reasons only main coefficients are included in Table 2. Interaction terms are briefly discussed in the next section and reported in appendix Table A1.

Table 3
Results of the econometric models – river system variables only.

	NB	NB w\ interactions
Blackwater	0.426***	0.0782
	(0.0788)	(0.216)
Moy	0.0758	−0.120
	(0.0671)	(0.192)
Laune	−0.221**	−0.674
	(0.110)	(0.411)
Corrib	0.210***	0.131
	(0.0795)	(0.187)
Lee	0.337**	−0.216
	(0.152)	(0.326)
Suir	1.675***	1.611***
	(0.130)	(0.174)
Feale	−0.346**	−0.302*
	(0.166)	(0.172)
Ballysadare	0.439***	−0.0460
	(0.103)	(0.409)
Drowes	0.181	−0.195
	(0.111)	(0.284)
Bandon	0.427***	−0.0124
	(0.164)	(0.295)
Nore	0.848***	0.845***
	(0.207)	(0.300)
Owenduff	−0.265	−0.232
	(0.220)	(0.222)
Owenea	0.439**	0.438*
	(0.182)	(0.244)
Ilen	0.619***	−0.587
	(0.167)	(0.411)
Shannon	1.098***	1.188***
	(0.192)	(0.251)
Waterville	−0.624***	0.448***
	(0.189)	(0.149)

Robust standard errors clustered at individual level in parentheses. *p < 0.10, **p < 0.05, ***p < 0.01.

problem for the data. There is also consistency across models, including Poisson specifications not reported here, with only changes in magnitude rather than sign of the estimated coefficients between models. The presence of overdispersion in the data was tested by a log-likelihood ratio test on the dispersion coefficient α in the NB models. For instance, in the first NB model the test returned a $\chi^2_{(1)}$ value of 6992.75 (p-value = 0.000) indicating that overdispersion is important and that the NB model is more appropriate to model the data. This conclusion is also supported by significant coefficients for α in both models.

The first analysis of the coefficients concerns fishing methods, with shrimp as a reference category. All the other methods have a negative coefficient, which suggests that all are less effective compared to shrimp as a bait for salmon angling. In particular, fishing with spinner is the method providing the lowest probability of catch, followed by worms and fly fishing. This ranking is the same across models, which is an additional indication of consistency of this analysis. This result was expected, as shrimp are considered a very effective bait for salmon and many local bye-laws either prohibit or curtail the use of shrimp as bait.

We include licence types to examine how catch rates vary across licences with the annual licence covering all districts as a reference category. The annual district-only licence has a positive coefficient, meaning that catch with this licence is more prolific than the annual geographically-unrestricted licence. Anglers with a juvenile licence catch less than anglers with a standard licence. A juvenile licence is for anglers under 18 years old and they are therefore less expert than anglers fishing for many years. Licences with 1 or 21 day duration have considerably lower probability of catching fish, which most likely reflects lower effort compared to anglers with season long licences. In particular, anglers with a daily licence have a very large and negative coefficient.

Anglers' country of origin is the only demographic variable available from the logbooks. Catches by anglers visiting from Great Britain and elsewhere in Europe are higher compared to those from the Republic of Ireland, whereas catches by anglers from Northern Ireland or elsewhere are not statistically different from Irish anglers. It is not clear why anglers from the Great Britain and Europe have higher catches. It may reflect higher relative skill levels of visiting anglers but the predominant fisheries where Great Britain and European anglers catch salmon are the two most prolific fisheries, the river Moy and the Munster Blackwater. Visiting anglers tend to concentrate on the premier salmon fisheries, whereas anglers living in the Republic of Ireland fish across all the salmon rivers. Visiting anglers might also be expected to be more likely to use the services of a gilly, which should increase their chances of catching a higher number of salmon, all else being equal.

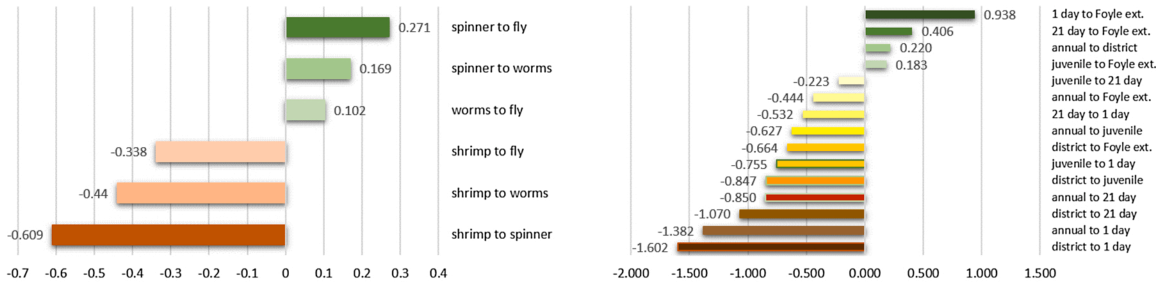
Table 4
Unconditional predicted mean catch and standard errors by fishing method and licence type.

	Predicted mean catch	Standard Error
Overall	1.37***	(0.09)
By fishing method:		
Shrimp	1.79***	(0.16)
Spinner	1.18***	(0.09)
Worms	1.35***	(0.10)
Fly	1.45***	(0.10)
By licence type:		
Annual	1.51***	(0.11)
District	1.73***	(0.11)
Juvenile	0.89***	(0.12)
21 day	0.66***	(0.07)
1 day	0.13**	(0.05)
Foyle Ext.	1.07***	(0.16)

*p < 0.10, **p < 0.05, ***p < 0.01.

In the regression models we included dummy variables for the 16 most prolific river systems in 2016 each with annual catches exceeding 300 fish, as illustrated in Fig. 1. These 16 river systems accounted for 81% of the total recreational catch for the 2016 season. The reference category is the remaining river systems. Although the dummy variables represent the most prolific fisheries compared to the reference category, it is not necessary for the estimated coefficients to be always positive, as the model is estimating catch per angler by river and method. The most prolific river systems also have the highest number of anglers so average catch per angler is not necessarily higher on the most prolific river systems. We report the regression coefficients for these dummy variables separately in Table 3. Controlling for the other explanatory variables in the model the results in Table 3 indicate average catch rates on the river Moy, the second most prolific river in the country, are not statistically different than the reference category, while mean angler catch on the Blackwater is higher, on the river Laune is lower compared to the reference category. The Suir river system has the highest coefficient estimate at 1.675. Controlling for fishing method, licence type, as well as angler country of origin, the river Suir has the highest mean catch per angler, though the coefficient itself cannot be interpreted directly as a number of fish. From the logbook returns mean catch per angler on the Suir using a fly as a fishing method is 8.7 salmon compared to 3.9 fish on the Blackwater. In general, the statistical significance of almost all river system coefficients highlights a high explanatory power for these variables and suggests that catch is site-specific, therefore angling location is an important factor.

The second NB model included interaction terms between fishing methods and rivers, on the premise that there may be non-linearities in the catch rates associated with particular river and fishing method combinations. The interaction terms are reported separately in the appendix Table A1. Just 9 of the 38 reported parameter estimates are statistically different than zero at the 5% level suggesting little added value from this model in terms of using the estimates to inform angling pressure or stock assessment at specific river level. However, collectively



(a) Fishing methods (b) Licence types

Fig. 3. Pairwise comparison of marginal effects.

Table 5
Marginal catch, cost and cost per fish for different licences.

Licence type	Predicted mean catch	Cost (€)	€ per fish
Annual	1.51	100	66.10
District	1.73	56	32.32
Juvenile	0.89	10	11.29
21 day	0.66	40	60.33
1 day	0.13	20	152.95
Foyle ext.	1.07	80	74.84

the 38 interaction terms are highly statistically significant with a $\chi^2_{(38)} = 176.5$ suggesting that the association between catch rates and river-fishing method combinations are non-linear. Consequently, in Table A1 we have also reported the mean predicted catch rates for the 16 top river systems associated the different fishing methods.

4.2. Postestimation and marginal effects

Table 4 shows model predicted mean catch rates associated with variables of policy interest, i.e. methods and licence types, calculated based on the model specified without interactions. The information that can be retrieved from these indicators is the predicted catch associated with the fishing method or licence type controlling for all other covariates, such as river systems. First, the overall model unconditional mean predicted catch is 1.37 salmon, which contrasts with the mean of 3.08 conditional on positive catch from Table 1. Table 4 shows how the unconditional mean catch varies by fishing method or licence type. Anglers using shrimp as a fishing method have a model mean catch of 1.79 salmon for the 2016 season, which is the highest of the four fishing methods, while those using a spinner as bait have the lowest mean catch of 1.18 salmon. With regard to licence types, as outlined earlier, anglers purchasing a district licence have the highest catch, estimated at 1.73 salmon, all else held equal. The annual licence is associated with the second largest bag, i.e. 1.51 salmon per season. The higher predicted catch for anglers with a district licence may be related to the degree of local knowledge of anglers frequently fishing in the same district rivers, compared to anglers with an annual licence covering all districts but who may not have the same in-depth experience at all fishing locations. Juvenile and time-limited licences show the lowest return in terms of catch, which is reasonable due to the likely lower degree of expertise or potentially lower fishing effort, particularly with the short duration licences. It is also feasible to calculate predicted mean catches associated with a combination of fishing methods or river systems. In the previous section we noted that the river Suir has the highest mean catch per angler. The model predicted mean catch rate for district licence holders, flying fishing on the river Suir is 7.1 (s.e. 0.94) salmon compared to a comparable angler on the Blackwater of 2.0 (s.e. 0.18).

Fig. 3 presents these results visually, where catch associated with licences types and fishing methods are evaluated as pairwise comparisons. In this case the general interpretation of the bars indicate the increase (or decrease) in the predicted mean catch when switching from one method or licence to another. With respect to fishing methods, switching from shrimp to spinners is associated with the largest decrease in the average catch of approximately 0.6 fish less on average, a switch from shrimp to worms or flies decreases mean catch by 0.45 and 0.32, respectively. Swapping spinners with fly fishing is associated with an average increase of 0.3 fish per season, while replacing spinners with worms is associated with an increase in mean catch of almost 0.2 fish per season. With respect to licences the largest difference in mean seasonal catch occurs between a district licence and the 1 or 21 days licences.

In Table 5 we show the catch (or return) per unit cost of a licence, i.e. the ratio of average catch by licence type to licence cost. An annual all-districts licence costs €100 and the mean catch of anglers with that licence is 1.51 salmon. The mean licence cost per fish caught is €66.10. Contrast that with the 1-day licence, the annual licence is five times the 1-day licence cost but the mean catch is over 11 times higher. The mean licence cost per fish caught for the 1-day licence is €152.95. Across the adult licences, the district licence has the lowest mean licence cost per fish caught at €33.32.

5. Discussion

With the abolition of all drift netting and most draft netting recreational angling is the primary catch-related pressure on salmon stocks in Ireland. Therefore, recreational harvest data is useful information to anticipate stock status for the following season. Other logbook programmes show the potential benefits of this sampling method on catch and effort assessment compared to traditional intercept creel surveys (Cooke & Cowx, 2006; Mosindy & Duffy, 2007; Starr, 2010). In this contribution we enrich the informative potential of logbook data analysis with the exploration of factors that are associated with catch, in particular fishing method and licence types. Information retrieved from angler logbooks is already being used to establish river specific conservation limits (White et al., 2016) and assess whether recreational harvesting is permitted. The models estimated here based on the same logbook data provides additional information useful for the regulation and management of recreational fisheries, including informing decisions on the regulation of fishing methods, catch and release, river-specific policies, licence types and costs, which are discussed in the next subsections.

5.1. Angling regulation

Angling regulation aimed to control fishing methods can be used to influence both the number of anglers and their catch rate. More effective fishing methods can be curtailed when managers are concerned about stocks. This would reduce the expected catch and discourage anglers specialising in the curtailed fishing methods from fishing. As seen in the model results, shrimp as a bait has the highest predicted catch and fishing by spinner has the lowest. Across all four fishing methods considered, the mean predicted catch is between 1–2 salmon per angler, per season, over all river systems. So, on average across all salmon rivers there is not a substantial difference between fishing methods. And on this basis one could conclude that fishing methods have been regulated in such a manner that no single fishing method, averaging across anglers and the entire season, is substantially more successful in catching salmon than any others. But averages obscure the distribution of outcomes on specific rivers. For example, there is a difference of 3 fish between the highest angler catch per method (shrimp, 8.7 fish) and and the lowest (spinner, 5.7 fish) on the river Suir. On the Blackwater river the difference is just 1.3 fish, with mean catch by shrimp at 2.5 fish compared to mean catch by spinner at 1.2 fish. The estimated model can be used to compare mean catch rates by fishing methods both within and between river systems for the purpose of reviewing regulations pertaining to specific rivers or fishing methods. With this information the regulation of angling methods can be reviewed with the objective of controlling total catch and protecting stock sustainability. At present fishery managers use variable exploitation rate bands to account for variable angling pressure and to estimate anglers' catch with the exploitation rates based on known angling catches in rivers with fish counter data (Millane et al., 2017).

5.2. Licences

Information on licence types may be important from several perspectives. The main challenge for fisheries management is balancing anglers' participation, which provides local economic benefits, with conservation and sustainability of fish stocks. The type of licence anglers buy may influence catch because it may reflect how often and where anglers fish and licence price is one of the determinants that fishery managers can manipulate to maintain a balance between angler participation and stock sustainability. The relative comparison of catch by licence type highlights that annual and district licences are those associated with the highest average catch per season, while time-constrained licences are less prolific on average. With this information fishery managers can assess in near real-time recreational angling pressure on fish stocks based on the number and types of licences sold. The large catch associated with district-licence holders suggests that anglers who only fish in one district have a deeper knowledge and experience of angling sites and that is reflected in higher catches. Anglers fishing across several districts (i.e. annual, all districts licence) may have lower levels of local knowledge, which is reflected in lower catches. As illustrated in Table 5, this information is useful to calculate the catch (or return) per unit cost of a licence. District licence holders, on average, enjoy the best value or returns in terms of the cost of their licence fee. The juvenile licence has the lowest cost per fish caught, which no doubt reflects a policy measure by fishery managers to encourage participation in recreational angling by young people. Short duration licences, i.e. 1 and 21 day licences, are frequently purchased by tourist and novice anglers, whose expertise in salmon fishing is likely to be lower than other salmon anglers. The lower probability of catch associated with these licences increases the ratio of licence cost to expected catch.

5.3. River systems

Rivers are very different from each other and finding management interventions suitable for all can be difficult. For this reason diversified policies based on river characteristics are often successful for conservation. In general, natural baits (i.e. worms, shrimps and prawns) are more successful catching salmon and require lower expertise compared to spinners and fly fishing. Natural baits are more heavily regulated to protection stock sustainability, but local regulations vary, which may be reflected in varying catch rates across river systems. The model estimates account for site specific effects reported in Table 3, including interaction effects between fishing methods and rivers systems, which are reported in Table A1. A couple of examples are provided to illustrate the diversity of research findings. The consequent implications for the management of these fisheries ultimately depends on the viability of the stocks in these rivers. These examples highlight which fishing methods are the most effective within a given fishery. Taking the river Ilen, it is noticeable that fly fishing and the spinner are particularly effective with predicted mean catch rates of 3.9 and 2.3 fish relative to worms as bait with a mean of 1.2 fish. These baits are substantially less effective in Waterville with predicted mean catch rates of 0.55–0.65. On the river Bandon fly fishers have a predicted mean catch of 2.5 salmon for the 2016 season, substantially higher than those using worms as bait with a predicted mean of just 0.4 fish. As noted earlier, the dataset does not include effort data and it is therefore not possible to scale the angling methods by effort levels, which complicates the interpretation of results for fishery management purposes. These examples illustrate the types of analysis that can be undertaken with more accurate data. Interactions enrich the informative potential of this analysis and identify the most and least effective methods by river, so that specific policies can be tailored if conservation is in danger.

5.4. Caveats

The methodology employed in the paper has some limitations to consider when interpreting our results and to improve the method in future applications. Firstly, and as discussed in the methodology section, we have ignored the panel nature of the data in the model estimation. If the catch rate is affected by unobservable variables that systematically vary across river-method in the panel, then the coefficient on any variable that is correlated with this variation will be biased. The use of weights in the chosen models allows us to account for the fact that observations from the same angler are related but an area for future research if the interest is on time-varying variables is to consider the use of a panel count model along the lines of Hynes and Greene (2016), though at present the structure of the logbook returns precludes the creation of a panel. Another important factor to note is that it is not possible to control for illegal, unreported and unregulated fishing. The accuracy of the results also depends on the reliability of logbooks, which is in turn determined by anglers' environmental consciousness and enforcement levels. Errors in logbook data compilation may be due to exaggerated catch, misidentification of species and measurement error of weight or length (Cooke & Cowx, 2006; Essig & Holliday, 1991). Irish rivers are carefully monitored to avoid illegal harvest and misreporting but avoiding poorly reported information cannot be guaranteed. However, the overall dataset is quite large so the individual contribution of any one observation on the estimated model coefficients will be small. Another limitation of the dataset was the absence of information on effort levels, e.g. the number of fishing days, as well as observations representing persons that did not catch at least one salmon. Complete information on effort and zero catch is advantageous and allows further analysis, for example CPUE assessment. An area for concern with our sample is whether the 30% of logbooks that are not returned are systematically different than the returned log-books, though it should be noted that official published catch statistics are adjusted to account for non-return of logbooks. As noted earlier the majority of non-returns are associated with 1-day licences, where catch rates are invariably low and well-addressed by a truncated model. However, if there is some other systematic reason why logbooks are not returned, e.g. related to geography or angler type, this may introduce bias in the estimates but we have no reason to suspect any organised or systematic association in failure to return logbooks.

6. Conclusions

Fishery managers are increasingly concerned about the environmental impacts caused by recreational anglers and attempt to avert negative outcomes through regulation. There is an increasing need to monitor anglers' activity given the wide evidence of environmental impact caused by recreational fishing. Currently, the tools available for managing recreational fisheries tend to place restrictions on individual anglers, such as daily catch limits and bag size limits. However, the effectiveness of these methods to restrict recreational catch have been questioned, as they may not effectively limit the total harvest (Chan, Beaudreau, & Loring, 2018; Cox, Beard, & Walters, 2002). Also, ecosystem impacts are caused by both the number of anglers and their catch; policies usually aim to reduce one or the other. Limiting the number of anglers might have negative economic consequences so reducing fish harvest is often preferred. In this contribution we propose a method to identify a ranking of fishing methods for salmon based on catch effectiveness, controlling for river specific characteristics such as habitat conditions and stocks. We argue that the analysis of logbook data to estimate the catch probabilities by fishing methods provides valuable information to fishery management, data on CPUE would be preferable. Along with other available biological data, the method and analysis presented here should facilitate fishery managers make better informed decisions on stock management.

This contribution discussed the logbook scheme operating in Ireland and proposed a methodology to analyse the data in a simple and at the same time informative manner. A major advantage of the approach suggested is that collecting data from logbooks is efficient and relatively cheap, both in terms of money and time. Self-compiled logbooks allow surveying the full population of anglers without the need of interviewers or costly surveys. The statistical analyses proposed here are quite simple to replicate and models are flexible enough to allow different specifications based on the objective of the study. As already highlighted, possible improvements of the models could be collecting additional angler-related variables such as experience, number of annual fishing occasions and socio-demographics to assess their causal effects on catch. In addition, this procedure is flexible and may be applied to many endangered fish species and also to different recreational activities involving pressure on natural stocks, e.g. hunting.

Considering the shortcomings of currently recorded logbook data, a recommendation for fisheries management is to try improve collection of angling effort information. At present data on total angling effort is requested but poorly reported. More granular effort data could be used to better understand how CPUE is associated with angler attributes or river system characteristics. There will always be the issue of a proportion of anglers not returning their logbooks and official catch statistics can be adjusted to allow for non-returns, nonetheless, research understanding the extent to which non-returns are non-random in a sampling sense would be beneficial.

In many river systems angling harvest is well under the total allowable catch (IFI, 2017a) and therefore there is scope within sustainability criteria to increase angler participation rates. The assessment of the ex-post expected value for money of licence types highlights the fact that the cost per fish caught is highest for the 1-day licence suggests fishery managers might consider the introduction of a special "come and try it" 1 day licence for beginners at a cost below the current 1 day licence if the goal is to try and encourage new participants in the sport of salmon angling.

Conflict of interest

The authors declare that there is no conflict of interest.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A

Table A1
Model parameter estimates for interaction terms and associated mean predicted catch rates.

Method	River	Parameter estimate, β	Standard error	Predicted mean catch, μ_c	Standard error
Shrimp	Moy	[a]		1.57	0.22
Shrimp	Ballysadare	[a]		1.69	0.65
Shrimp	Drownes	[a]		1.46	0.37
Shrimp	Corrib	[a]		2.02	0.27
Shrimp	Nore	[a]		4.11	1.11
Shrimp	Blackwater	[a]		1.91	0.32
Shrimp	Laune	[a]		0.90	0.35
Shrimp	Waterville	[a]		2.77	0.16
Shrimp	Lee	[a]		1.42	0.42
Shrimp	Bandon	[a]		1.75	0.46
Shrimp	Ilen	[a]		0.98	0.38
Spinner	Owenea	−0.008	0.382	1.68	0.48
Spinner	Moy	−0.113	0.224	0.86	0.09
Spinner	Ballysadare	0.440	0.523	1.62	0.52
Spinner	Drowes	0.630	0.332	1.69	0.29
Spinner	Corrib	−0.203	0.268	1.02	0.19
Spinner	Shannon	−0.326	0.372	2.58	0.70
Spinner	Suir	0.034	0.259	5.65	1.02
Spinner	Nore	0.237	0.376	3.22	1.03
Spinner	Blackwater	0.006	0.24	1.19	0.11
Spinner	Feale	−0.110	0.318	0.72	0.19
Spinner	Laune	0.447	0.441	0.87	0.14
Spinner	Waterville	−0.962	0.32	0.65	0.18
Spinner	Lee	0.498	0.404	1.45	0.33
Spinner	Bandon	0.400	0.335	1.61	0.27
Spinner	Ilen	1.336	0.458	2.31	0.46

(continued on next page)

Table A1 (*continued*)

Method	River	Parameter estimate, β	Standard error	Predicted mean catch, μ_c	Standard error
Worms	Owenea	−0.418	0.518	0.96	0.42
Worms	Moy	0.481	0.23	1.35	0.11
Worms	Ballysadare	0.565	0.439	1.58	0.20
Worms	Drownes	0.510	0.402	1.29	0.35
Worms	Corrib	0.249	0.25	1.37	0.18
Worms	Blackwater	0.379	0.325	1.48	0.33
Worms	Feale	−2.424	1.021	0.06	0.06
Worms	Laune	0.674	0.458	0.94	0.16
Worms	Waterville	−0.989	0.337	0.55	0.16
Worms	Lee	−0.256	0.451	0.58	0.17
Worms	Bandon	−0.831	0.439	0.40	0.12
Worms	Ilen	0.809	0.462	1.17	0.22
Fly fishing	Owenea	[a]		1.75	0.43
Fly fishing	Owenduff	[a]		0.90	0.19
Fly fishing	Moy	0.162	0.225	1.18	0.13
Fly fishing	Ballysadare	0.604	0.438	1.98	0.31
Fly fishing	Drownes	0.143	0.311	1.07	0.16
Fly fishing	Corrib	0.102	0.223	1.43	0.17
Fly fishing	Shannon	[a]		3.71	0.92
Fly fishing	Suir	[a]		5.67	0.93
Fly fishing	Nore	−0.687	0.360	1.32	0.26
Fly fishing	Blackwater	0.636	0.249	2.31	0.26
Fly fishing	Feale	[a]		0.84	0.14
Fly fishing	Laune	0.056	0.462	0.61	0.13
Fly fishing	Waterville	−1.179	0.309	0.55	0.15
Fly fishing	Lee	0.722	0.395	1.88	0.41
Fly fishing	Bandon	0.811	0.406	2.52	0.69
Fly fishing	Ilen	1.816	0.542	3.87	1.35

Note: Other parameter estimates are reported in Tables 2 and 3.
[a] Interaction term not estimated.

References

AAAS. (1997). Ice age communities may be earliest known net hunters. *Science, 277* (5330), 1203–1204. https://doi.org/10.1126/science.277.5330.1203.

Anderson, L., & Thompson, P. (1991). Development and implementation of the angler diary monitoring program for great bear lake, northwest territories. *Creel and angler surveys in fisheries management, American Fisheries Society, Symposium (Vol. 12)*, 457–475.

Angling Ireland. (2018). *Salmon fishing in Ireland*. http://www.fishinginireland.info/salmon/salmon.htm.

Arlinghaus, R., Tillner, R., & Bork, M. (2015). Explaining participation rates in recreational fishing across industrialised countries. *Fisheries Management and Ecology, 22*(1), 45–55.

Baltagi, B. (2013). *Econometric analysis of panel data* (5th ed.). Chichester, United Kingdom: John Wiley & Sons.

Cambray, J. A. (2003). Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. *Hydrobiologia, 500*(1–3), 217–230.

Cameron, A. C., & Trivedi, P. K. (1986). Econometric models based on count data. Comparisons and applications of some estimators and tests. *Journal of Applied Econometrics, 1*(1), 29–53. https://doi.org/10.1002/jae.3950010104.

Camp, E. V., Larkin, S. L., Ahrens, R. N., & Lorenzen, K. (2017). Trade-offs between socioeconomic and conservation management objectives in stock enhancement of marine recreational fisheries. *Fisheries Research, 186*, 446–459.

Carpenter, S. R., Brock, W. A., Hansen, G. J., Hansen, J. F., Hennessy, J. M., Isermann, D. A., et al. (2017). Defining a safe operating space for inland recreational fisheries. *Fish and Fisheries, 18*(6), 1150–1160.

Chan, M. N., Beaudreau, A. H., & Loring, P. A. (2018). Evaluating the recreational fishery management toolbox: Charter captains' perceptions of harvest controls, limited access, and quota leasing in the guided halibut fishing sector in Alaska. *Marine Policy, 91*, 129–135. https://doi.org/10.1016/j.marpol.2018.02.013.

Cooke, S. J., & Cowx, I. G. (2006). Contrasting recreational and commercial fishing: Searching for common issues to promote unified conservation of fisheries resources and aquatic environments. *Biological Conservation, 128*(1), 93–108. https://doi.org/10.1016/j.biocon.2005.09.019.

Cookie, S., & Cowx, I. (2005). The role of recreational fishing in global fish crisis. *Bioscience, 54*, 857–859.

Cox, S. P., Beard, T. D., & Walters, C. (2002). Harvest control in open-access sport fisheries: Hot rod or asleep at the reel? *Bulletin of Marine Science, 70*(2), 749–761.

Curtis, J., Breen, B., O'Reilly, P., & O'Donoghue, C. (2017). The economic contribution of a recreational fishery in a remote rural economy. *Water Resources and Rural Development, 10*, 14–21. https://doi.org/10.1016/j.wrr.2017.11.001.

Curtis, J. A. (2002). Estimating the demand for salmon angling in Ireland. *Economic and Social Review, 33*(3), 319–332. http://hdl.handle.net/2262/59840.

Dayton, P. K. (1998). Reversal of the burden of proof in fisheries management. *Science, 279*(5352), 821–822.

DCCAE. (2018). *Conservation of Salmon and Sea Trout (Catch and Release) Bye-Law No. 967 of 2018*. https://www.fisheriesireland.ie/extranet/fisheries-management-1/salmon/salmon-regulations-2019/1571-conservation-of-salmon-and-sea-trout-catch-and-release-bye-law-no-967-of-2018/file.html.

Englin, J., Lambert, D., & Shaw, W. D. (1997). A structural equations approach to modeling consumptive recreation demand. *Journal of Environmental Economics and Management, 33*(1), 33–43. https://doi.org/10.1006/jeem.1996.0976.

Essig, R., & Holliday, M. (1991). Development of a recreational fishing survey: The marine recreational fishery statistics survey case study. *American Fisheries Society Symposium (Vol. 12)*, 245–254.

Gagne, T. O., Ovitz, K. L., Griffin, L. P., Brownscombe, J. W., Cooke, S. J., & Danylchuk, A. J. (2017). Evaluating the consequences of catch-and-release recreational angling on golden dorado (*Salminus brasiliensis*) in Salta, Argentina. *Fisheries Research, 186*, 625–633.

Greene, W. H. (2003). *Econometric Analysis*. Pearson Education India.

Grilli, G., Curtis, J., Hynes, S., & O'Reilly, P. (2018). Sea bass angling in Ireland: A structural equation model of catch and effort. *Ecological Economics, 149*(3), 285–293.

Hartill, B., & Thompson, F. (2016). *Review of self-reporting tools for recreational fishers (New Zealand Fisheries Assessment Report 06)*.

Hilbe, J. M. (2011). *Negative binomial regression*. Cambridge University Press.

Hutchings, J. A. (2000). Collapse and recovery of marine fishes. *Nature, 406*(6798), 882.

Hynes, S., Gaeven, R., & O'Reilly, P. (2017). Estimating a total demand function for sea angling pursuits. *Ecological Economics, 134*, 73–81. https://doi.org/10.1016/j.ecolecon.2016.12.024.

Hynes, S., & Greene, W. (2016). Preference heterogeneity in contingent behaviour travel cost models with on-site samples: A random parameter vs. a latent class approach. *Journal of Agricultural Economics, 67*(2), 348–367. https://doi.org/10.1111/1477-9552.12143.

IFI. (2017). *The status of Irish salmon stocks in 2016 with precautionary catch advice for 2017*. Citywest, Dublin: Inland Fisheries Ireland. https://www.fisheriesireland.ie/documents/1412-the-status-of-irish-salmon-stocks-in-2016-with-precautionary-catch-advice-for-2017/file.html.

IFI. (2017). *Wild salmon and sea trout fisheries statistics report 2016 (IFI/2017/1-4374)*. Citywest, Dublin: Inland Fisheries Ireland. https://www.fisheriesireland.ie/extranet/fisheries-management-1/1461-wild-salmon-and-sea-trout-statistics-report-2016/file.html.

IFI. (2019). *Inland Fisheries Ireland summary fish counter report 2018 (IFI/2019/1-4462)*. Citywest, Dublin: Inland Fisheries Ireland. https://www.fisheriesireland.ie/extranet/fisheries-management-1/salmon/1597-annual-fishcounter-summary-report-2018/file.html.

Jankovský, M., Boukal, D., Pivnička, K., & Kubečka, J. (2011). Tracing possible drivers of synchronously fluctuating species catches in individual logbook data. *Fisheries Management and Ecology, 18*(4), 297–306.

Jansen, T., Arlinghaus, R., Als, T. D., & Skov, C. (2013). Voluntary angler logbooks reveal long-term changes in a lentic pike, *Esox Lucius*, population. *Fisheries Management and Ecology, 20*(2–3), 125–136. https://doi.org/10.1111/j. 1365-2400.2012.00866.x.

Kerr, S. J. (2007). Characteristics of Ontario muskellunge (*Esox masquinongy*) fisheries based on volunteer angler diary information. *Environmental Biology of Fishes, 79* (1–2), 61–69.

Lawrence, K. (2005). Assessing the value of recreational sea angling in South West England. *Fisheries Management and Ecology, 12*(6), 369–375. https://doi.org/10.1111/j. 1365-2400.2005.00465.x.

Lewin, W.-C., Arlinghaus, R., & Mehner, T. (2006). Documented and potential biological impacts of recreational fishing: Insights for management and conservation. *Reviews in Fisheries Science, 14*(4), 305–367. https://doi.org/10.1080/10641260600886455.

Maunder, M. N., Sibert, J. R., Fonteneau, A., Hampton, J., Kleiber, P., & Harley, S. J. (2006). Interpreting catch per unit effort data to assess the status of individual stocks and communities. *ICES Journal of Marine Science, 63*(8), 1373–1385.

McPhee, D. P., Leadbitter, D., & Skilleter, G. (2002). Swallowing the bait: Is recreational fishing in Australia ecologically sustainable? *Pacific Conservation Biology, 8*(1), 40–51. https://doi.org/10.1071/PC020040.

Millane, M., Shephard, S., White, J., Ó Maoiléidigh, N., O'Higgins, K., O'Malley, P., et al. (2017). Estimating salmonid angling exploitation rates from systems monitored by fish counters, and potential application to fisheries management in Ireland. *Sea Trout: Science & Management. Proceedings of the 2nd International Sea Trout Symposium*, 167–184.

Morey, E. R., & Waldman, D. M. (1998). Measurement error in recreation demand models: The joint estimation of participation, site choice, and site characteristics. *Journal of Environmental Economics and Management, 35*(3), 262–276. https://doi.org/10.1006/jeem.1998.1029.

Mosindy, T. E., & Duffy, M. J. (2007). The use of angler diary surveys to evaluate long-term changes in muskellunge populations on Lake of the Woods, Ontario. *Environmental Biology of Fishes, 79*(1–2), 71–83.

Mundlak, Y. (1978). On the pooling of time series and cross section data. *Econometrica: Journal of the Econometric Society*, 69–85. https://www.jstor.org/stable/1913646.

Pollock, K. H., Jones, C. M., & Brown, T. L. (1995). Angler survey methods and their application in fisheries management. *Reviews in Fish Biology and Fisheries, 5*(3), 378–380. https://doi.org/10.1007/BF00043009.

Prince, E. D., Ortiz, M., & Venizelos, A. (2002). A comparison of circle hook and "j" hook performance in recreational catch-and-release fisheries for billfish. *American Fisheries Society Symposium*, 66–79.

Ready, R. C., Poe, G. L., Lauber, T. B., Connelly, N. A., Stedman, R. C., & Rudstam, L. G. (2018). The potential impact of aquatic nuisance species on recreational fishing in the Great Lakes and Upper Mississippi and Ohio River Basins. *Journal of Environmental Management, 206*, 304–318.

Schroeder, D. M., & Love, M. S. (2002). *Recreational fishing and marine fish populations in California* (pp. 182–190). California Cooperative Oceanic Fisheries Investigations Report.

Starr, P. (2010). Fisher-collected sampling data: Lessons from the New Zealand experience. *Marine and Coastal Fisheries, 2*(1), 47–59.

Stephens, A., & MacCall, A. (2004). A multispecies approach to subsetting logbook data for purposes of estimating CPUE. *Fisheries Research, 70*(2–3), 299–310.

Toivonen, A.-L., Roth, E., Navrud, S., Gudbergsson, G., Appelblad, H., Bengtsson, B., et al. (2004). The economic value of recreational fisheries in Nordic countries. *Fisheries Management and Ecology, 11*(1), 1–14.

van der Hammen, T., de Graaf, M., & Lyle, J. M. (2015). Estimating catches of marine and freshwater recreational fisheries in the Netherlands using an online panel survey. *ICES Journal of Marine Science, 73*(2), 441–450. https://doi.org/10.1093/icesjms/fsv190.

White, J., Ó Maoiléidigh, N., Gargan, P., de Eyto, E., Chaput, G., Roche, W., et al. (2016). Incorporating natural variability in biological reference points and population dynamics into management of Atlantic salmon (*Salmo salar* L.) stocks returning to home waters. *ICES Journal of Marine Science, 73*(6), 1513–1524. https://doi.org/10.1093/icesjms/fsw015.

Zarauz, L., Ruiz, J., Urtizberea, A., Andonegi, E., Mugerza, E., & Artetxe, I. (2015). Comparing different survey methods to estimate European sea bass recreational catches in the Basque Country. *ICES Journal of Marine Science, 72*(4), 1181–1191. https://doi.org/10.1093/icesjms/fsv054.