Received: 25 August 2015 | Revised: 7 September 2016 | Accepted: 16 October 2016
DOI: 10.1002/aqc.2736

WILEY

RESEARCH ARTICLE

Effectiveness of shore-based remote camera monitoring for quantifying recreational fisher compliance in marine conservation areas

Darienne Lancaster[1] | **Philip Dearden**[2] | **Dana R. Haggarty**[3] | **John P. Volpe**[1] | **Natalie C. Ban**[1]

[1] School of Environmental Studies, University of Victoria, Victoria, BC, Canada
[2] Geography Department, University of Victoria, Victoria, BC, Canada
[3] University of British Columbia, Vancouver, BC, Canada

Correspondence
D. Lancaster, School of Environmental Studies, University of Victoria, David Turpin Building, B243. PO Box 1700 STN CSC. Victoria, BC V8W 2Y2, Canada.
Email: dlancaster@live.ca

Abstract

1. Marine conservation areas require high levels of compliance to meet conservation objectives, yet little research has assessed compliance quantitatively, especially for recreational fishers. Recreational fishers take 12% of global annual fish catches. With millions of people fishing from small boats, this fishing sector is hard to monitor, making accurate quantification of non-compliance an urgent research priority.
2. Shore-based remote camera monitoring was tested for quantifying recreational non-compliance in near-shore, coastal rockfish conservation areas (RCAs) in the Salish Sea, Canada.
3. Six high definition trail cameras were used to monitor 42 locations between July and August 2014.
4. Seventy-nine percent of monitored conservation area sites showed confirmed or probable fishing activity, with no significant difference in fishing effort inside and outside RCAs.
5. Mixed effects generalized linear models were used to test environmental and geographic factors influencing compliance. Sites with greater depth had significantly higher fishing effort, which may imply high, barotrauma-induced, rockfish mortality in RCA sites.
6. Non-compliance estimates were similar to aerial fly-over compliance data from 2011, suggesting that trail camera monitoring may be an accurate and affordable alternative method of assessing non-compliance in coastal conservation areas, especially for community-based organizations wishing to monitor local waters.
7. Widespread non-compliance could compromise the ability of RCAs to protect and rebuild rockfish populations. Increased education, signage, and enforcement is likely to improve compliance.

KEYWORDS
coastal, fish, fishing, marine protected area, marine reserve, ocean, recreation

1 | INTRODUCTION

Fishing has depleted marine resources, with large and long-lived marine species experiencing the greatest impacts (Cook, Sinclair, & Stefansson, 1997; Molfese, Beare, & Hall-Spencer, 2014; Pauly et al., 2002). To stem declines and promote recovery, many governments now use marine spatial management tools, such as marine protected areas (MPAs) and fisheries closures (Marinesque, Kaplan, & Rodwell, 2012). However, such tools require high levels of compliance to be effective, and even low levels of non-compliance can significantly diminish efficacy (Arias, 2015; Edgar et al., 2014; Graham et al., 2011; Little et al., 2005).

Many commercial fisheries are well monitored (e.g. fishery observers/electronic monitoring), however, this is rarely the case for recreational fishing (Bergseth, Russ, & Cinner, 2013; Cooke & Cowx, 2004). Yet recreational fishers take 12% of the total annual global marine catch, which comes primarily from coastal areas where the majority of small conservation areas are located (Cooke & Cowx, 2004; Marinesque et al., 2012). Thus, recreational non-compliance may seriously jeopardize the ability of marine

Copyright © 2017 John Wiley & Sons, Ltd.

conservation areas to protect target species and their habitats (Edgar et al., 2014).

Although rare compared with assessments of commercial fisheries, several studies have quantified recreational fisher compliance (Arias & Sutton, 2013; Greenberg & Godin, 2015; Smallwood & Beckley, 2012; Watson, Murray, Schaefer, & Bonner, 2015). These compliance studies have used several methods: direct questioning through surveys, law enforcement records, expert opinion, and indirect and direct observations (Bergseth et al., 2013). However, each method has its own challenges. Direct questioning, for example, is an affordable and relatively reliable method of assessing compliance, but response bias – the desire to answer questions in a socially acceptable way – can lead to underestimation of non-compliance (Arias & Sutton, 2013; Daw, Cinner, McClanahan, Graham, & Wilson, 2011). Law enforcement records offer valuable on-the-water data but sanctioning is typically discretionary, with many violators receiving warnings leading to underestimates of non-compliance (Bell, 1997; Robbins, Hisano, Connolly, & Choat, 2006). Expert opinion relies on managers or community leaders with extensive knowledge of specific conservation areas and activities within them, but is subject to expert bias (Martin et al., 2012). Indirect observation involves quantifying signs of illegal activity, such as blast craters on coral reefs or discarded fishing line (Williamson, Ceccarelli, Evans, Hill, & Russ, 2014). These techniques are rarely used, and quantifying non-compliance during specific temporal periods is challenging (Williamson et al., 2014).

Direct observations are promising in observing recreational fisher non-compliance, yet also have limitations. Direct observations typically use air, vessel, or shore-based methods (Bergseth et al., 2013). Aerial fly-over and vessel-based methods can be expensive and typically only offer a snapshot of non-compliance (Cudney-Bueno & Basurto, 2009; Smallwood & Beckley, 2012). Identification of non-compliant activities can also be difficult from the air, while vessel-based observations often signal their presence to possible violators who leave or conceal their activities when approached (Bergseth et al., 2013). Shore observations are promising for near-shore conservation areas frequented by recreational fishers, yet typically require long hours of observer monitoring in many sites. This can be expensive and difficult to coordinate with limited personnel and can introduce multiple observer variation (Ames & Schindler, 2009; Smallwood & Beckley, 2012). Shore-based camera and video monitoring is just beginning to be explored as a compliance monitoring tool (Ames & Schindler, 2009; Watson et al., 2015). Trail cameras are small and difficult to see, making them less susceptible to observer presence bias (i.e. when fishers alter behaviour based on the presence of an observer) (Bergseth et al., 2013). The Freshwater Fisheries Society of British Columbia (BC) uses cameras to monitor recreational fishing effort on small lakes (Greenberg & Godin, 2015), and video monitoring has been used to monitor recreational non-compliance in UK MPAs and recreational fishing in Oregon, USA (Ames & Schindler, 2009; Watson et al., 2015).

The purpose of this study was threefold. First, the efficacy of time-efficient, low cost (~ US $200 each) trail cameras was tested for near-shore monitoring. Second, this technique was used to quantify recreational fisher compliance within rockfish conservation area (RCA) boundaries as compliance is low in the region (Haggarty, Martell, & Shurin, in press; Lancaster, Dearden, & Ban, 2015). These results were then compared with a past study of RCA compliance and previously tested compliance influencers (Haggarty et al., in press). Then lastly, GIS layers were interrogated to reveal consistent underlying geo-physical factors associated with non-compliant activity. This paper also reflects on the promise and challenges of camera monitoring, and suggests improvements and additional applications.

2 | METHODS

2.1 | Case study

Rockfish conservation areas (RCAs) were created along the coast of British Columbia (BC), Canada, between 2003 and 2007 to protect declining inshore rockfish populations (yelloweye (*Sebastes ruberrimus*), quillback (*Sebastes malinger*), tiger (*Sebastes nigrocinctus*), copper (*Sebastes caurinus*), and China rockfish (*Sebastes nebulosus*)) (Yamanaka & Logan, 2010). Inshore rockfish are long-lived (50–120 years), slow growing fish found throughout BC waters (Love, Yoklavich, & Thorsteinson, 2002). They are susceptible to barotrauma (typically fatal injuries associated with ascending rapidly from depth), and have high site fidelity, which makes them vulnerable to overfishing (Parker et al., 2000). The development of a commercial rockfish fishery in the 1980s led to peak catches in the 1990s with subsequent steep declines (Yamanaka, Lacko, & Secretariat, 2001). For example, yelloweye rockfish are currently at 12% of their 1918 abundance (DFO, 2012) and are currently listed as a species of special concern, and quillback rockfish are listed as threatened (COSEWIC, 2009a, 2009b; SARA, 2014). Rockfish conservation areas were implemented as part of the Rockfish Conservation Strategy that also reduced total allowable catch quotas for commercial fishers by 75% in inside waters (all waters between Vancouver Island and the mainland), and daily bag limits for recreational fishers (reduced from five to one rockfish in inside waters) (Yamanaka & Logan, 2010). Rockfish conservation areas restrict all recreational fishing activity except for invertebrates by hand picking and trapping, and smelt (*Hypomesus pretiosus*) by gillnet (DFO, 2014).

This study took place in the Salish Sea (Strait of Georgia, Puget Sound, and Strait of Juan de Fuca). The Salish Sea is one of the most intensive recreational fishing areas in BC, with coho (*Oncorhynchus kisutch)* and chinook salmon *(O. tshawytscha*) driving the fishery (Zetterberg, Watson, & O'Brien, 2010). Recreational fishers take 90% of the annual rockfish harvest in the Strait of Georgia (Haggarty et al., in press). Not surprisingly, rockfish are most threatened in this region of BC, which also contains two- thirds of all RCAs (Yamanaka & Logan, 2010). BC's commercial groundfish fisheries have 100% on-board observer or electronic monitoring (Yamanaka & Logan, 2010). However, compliance data are limited for the recreational sector, with the Department of Fisheries and Oceans (DFO) relying upon sporadic vessel and plane-based patrols, and annual creel surveys (Haggarty et al., in press; Zetterberg et al., 2010).

2.2 | Remote camera monitoring

Six Bushnell HD trail cameras (model #119537C) were deployed in 32 shore locations overlooking 14 RCAs and 10 shore locations not protected by an RCA designation (hereafter called 'unprotected') in the Salish Sea (Figure 1). Owing to budget restrictions only six cameras were purchased and moved weekly to provide maximum coverage during the peak 2014 recreational fishing season (July and August). Most (85%) of the recreational effort in the Salish Sea occurs between May and September and BC's saltwater fishing effort is at its highest and remains relatively consistent between early July and late August (Zetterberg et al., 2010). Camera monitoring during this time period is presumed to maximize the capture of non-compliance events. Camera monitoring sites were prioritized in RCAs to maximize coverage of these conservation areas. Unprotected monitoring sites were added to facilitate a secondary, inside/outside RCA fishing pressure comparison. Specific monitoring locations were selected based on availability (e.g. public land or private property with owners' permission). Cameras were deployed for a minimum of five and a half days and a maximum of 14 days per site (mean = six and a half days). All cameras monitored a minimum of one full weekend (Friday evening to Sunday evening) and at least three and a half week days. The cameras were set to automatically take a picture every 5 minutes during daylight hours, from 4:30 am to 10:00 pm daily (*field scan* function). Cameras have a field of view (FOV) of 50° with resolution to 1 km. Cameras were placed to maximize ocean coverage in the FOV (Figure 2); total ocean cover varied from location to location (min = ~60% coverage, max =100% coverage). Cameras were locked to trees or upright structures with small signs explaining the research project, and noting that no individuals or boats would be identified during the research. Three RCA sites and one reference site were removed from the analysis due to poor photo quality or close proximity to another camera site, resulting in 29 RCA and nine reference sites. In some cases camera FOVs overlapped, however, all fishing events at

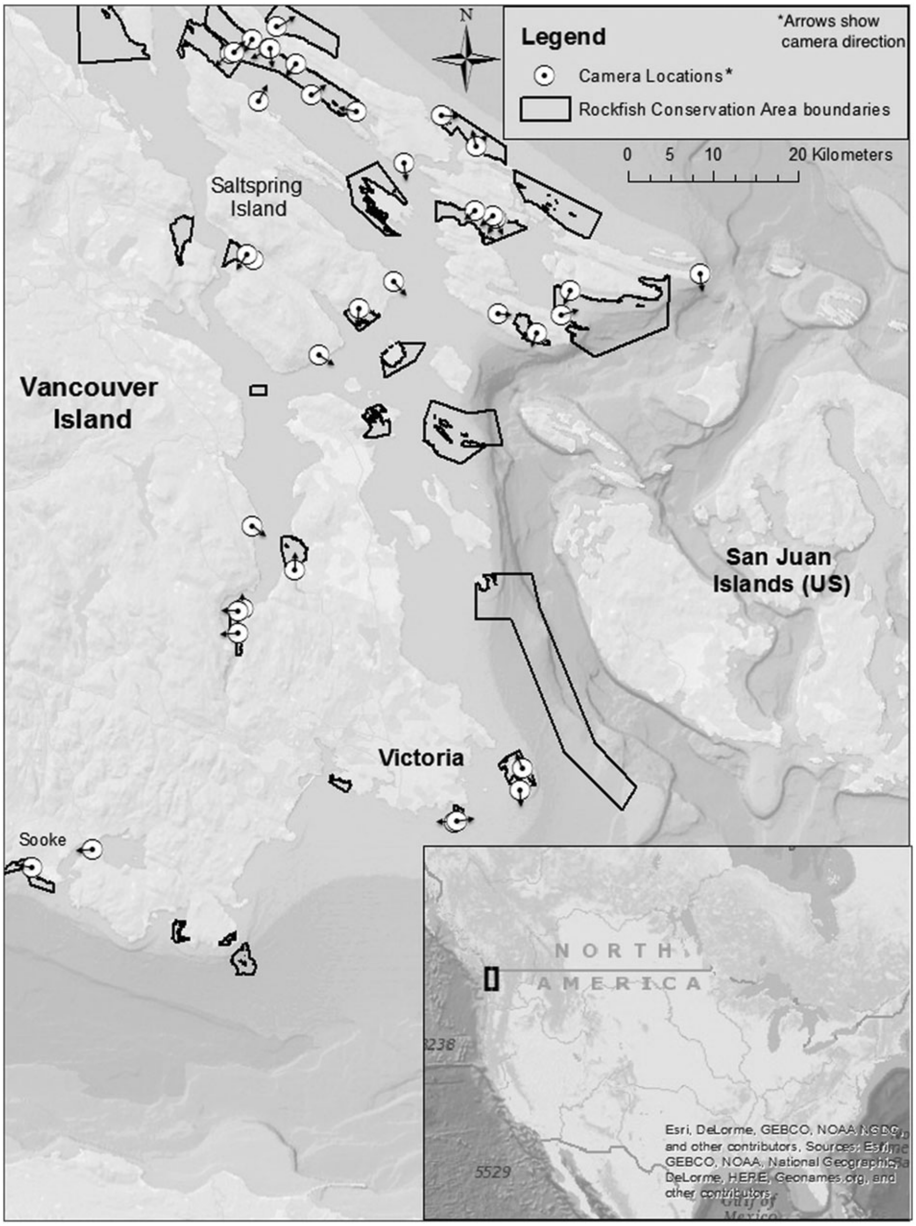

FIGURE 1 Rockfish Conservation Area (black outlines) and unprotected area remote trail camera monitoring locations (July–August 2014) in the Salish Sea, British Columbia, Canada. Trail cameras were placed on shore overlooking RCAs to capture recreational fisher non-compliance events, and non-RCA locations for comparison. Arrows indicate camera direction

FIGURE 2 Example of the field of view from a remote trail camera set up to monitor recreational fishing activity in the Salish Sea, British Columbia, Canada. Inset shows close-up of confirmed fishing event in an unprotected area

overlapping sites were compared and timestamp cross-referenced to ensure the same event was not recorded multiple times.

In total, ~60 000 photos were analysed for fishing events, with each site (~1500 photos) requiring approximately 15–20 minutes to process. Fishing events were identified based on presence of fishing gear in the water, boat type, boat movement patterns, and wake size. Most cameras were placed in locations where only RCA protected waters were visible or where a geographic marking provided a reference for RCA boundaries. In cases where geographic markers were absent, only boats close enough to shore to ensure 100% confidence of RCA boundary violation were counted. Images were labelled as ‘confirmed fishing’ when fishing gear (e.g. rod and line) were clearly visible in the water (Figure 2). Images were labelled as ‘probable fishing’ when: (1) fishing-style boats were captured in one or more frames with no wake to imply movement (suggesting jigging – defined as jerking a weighted line and hook up and down in a stationary position); or (2) fishing-style boats repeatedly circled into the camera field of view (suggesting trolling – defined as towing a weighted hook and line behind a slow moving boat). Site location, date, time, and duration of fishing events were recorded. These data were used to expose temporal trends in fishing pressure (e.g. morning vs. afternoon; weekdays vs. weekends), in RCA and unprotected sites.

Statistical analyses were then performed to determine if fishing effort was higher in reference sites than RCAs, and to assess environmental and geographic factors contributing to fishing effort. Using raw count data, mixed effect generalized linear models (GLMMs) were created in the statistical software R (R Core Team, 2013) using *glmer* from the package *lme4* (Bates, Maechler, & Bolker, 2014) with a Poisson distribution and log-link to account for variability in monitoring times between sites. GLMMs do not make assumptions about normal (Gaussian) distributions. A random effect was used to link camera sites to fishing events that occurred in those locations. Environmental and geographic predictor variables were included as fixed effects to determine whether certain characteristics enhance the likelihood of fishing events. ArcGIS layers available from the BC Marine Conservation Analysis (BCMCA, 2015) were used in GIS to create ecological predictor variables (Table 1). Sites with optimal rockfish habitat (Ardron & Wallace, 2015; Cloutier, 2011; Richards, 1986) – high rugosity, hard bottoms, greater depth (>20 m), and kelp presence – were hypothesized to attract higher fishing effort. Owing to the coarse resolution of these layers (Table 1), habitat types within camera FOVs were classified broadly. For example, if more than 50% of a camera FOV was covered by the high rugosity layer, that site was coded as high rugosity. Similarly, depth was coded based on the dominant depth category present in the FOV of the camera.

A separate GLMM was run that excluded unprotected reference sites, with a random effect linking entire RCAs (not individual monitoring sites) to fishing events. This GLMM tested if the total area of RCAs and RCA perimeter to area ratio influenced compliance, as was found in the study by Haggarty et al. (in press). Distance to boat launches, and terrestrial park presence at camera monitoring locations were originally included in an analysis of RCA and reference sites as was done by Haggarty et al. (in press). However, when these additional factors showed no correlation with fishing pressure, they were removed in order to test RCA specific variables (RCA total area, RCA perimeter to area ratio). Distance to population centres was not tested owing to the regions relatively homogeneous accessibility and use rates.

A subtractive selection method – step-by-step removal of predictor variables with the highest *P*-value – was used to identify the most parsimonious GLMMs. Each GLMM was compared with the previous

TABLE 1 GLMM ecological and geographic predictor variables, classification parameters, and GIS layer sources and specifications at camera monitoring sites

Ecological predictor variable	Classification parameters	GIS layer source and specifications
Rugosity	High = >50% of FOV Low = <50% of FOV	High rugosity layer- rugosity defined by the Nature Conservancy's Benthic Terrain Mapping (75 × 75 m resolution)
Bottom type	Dominant bottom type in FOV: Muddy Sandy Hard	Benthic classes layer -bottom classification defined by British Columbia Marine Ecological Classification (75 × 75 m resolution) (Ministry of Sustainable Resource Management, 2002)
Depth	Dominant depth range in FOV: 0–20 m 20–50 m 50–200 m >200 m	Benthic classes layer – ecologically significant depth ranges defined by British Columbia Marine Ecological Classification (75 × 75 m resolution) (Ministry of Sustainable Resource Management, 2002)
Bullkelp bioband	Presence or absence in FOV	Bullkelp bioband layer- extracted through provincial shore-zone mapping (400 m long shoreline scans) No other kelp layers publicly available

model with the R function *anova* to check for significant changes between models that could signal significant loss of explanatory power because of parameter deletion. Models with the greatest number of significant variables in combination with lowest Akaike Information Criterion (AIC) score were selected (Akaike, 1974). Marginal and conditional R^2 values were calculated for models with significant variables using a method developed by Nakagawa and Schielzeth (2013).

The percentage of RCA and reference sites with fishing activity was calculated, as well as the mean number of fishing events (MFE) per half day monitored. Number of fishing events was used as a measure of compliance instead of fishing duration owing to the camera's small FOV, which cannot capture prolonged fishing events in adjacent areas. Half days were chosen as the unit of measurement to ensure that data captured on a set-up or collection day could still be used. To determine the MFE per RCA per month, the MFE/half day monitored per site was used. Some RCAs had more than one camera monitoring site. To account for this, all the MFE/half day per site within a single RCA were summed and then divided by the number of camera sites in that RCA. This number was multiplied by 62 (the number of half days in both August and July when monitoring occurred).

To test the reliability of trail camera compliance monitoring, trail camera MFE data were then compared with aerial survey MFE estimates from July and August 2011 from Haggarty et al. (in press). Because of the temporal and methodological differences in these datasets, this comparison only highlights major differences in compliance rates between methods, and does not offer insight to fishing effort changes. Haggarty et al. (in press) digitized and georeferenced aerial survey data from DFO creel surveys (6–10 surveys per month) to measure RCA compliance. In order to compare MFE per month in RCAs across two different monitoring techniques (trail camera and aerial survey) each dataset was standardized using the package *arm* and function *rescale* in R (Gelman & Su, 2015). The rescale function standardizes variables by centering and dividing by two standard deviations (Gelman & Su, 2015). Thus, standardized means are not representative of 'real' fishing events per month and many RCAs with fishing effort may show negative standardized means. Average 'real' monthly fishing events were not available from Haggarty et al. (in press) because it was not possible to expand the standardized fishing effort estimates to monthly estimates of total effort. A Wilcoxon signed-rank test was used to compare the standardized means from each data set. Fishing effort in each RCA for each year was then ranked numerically and categorically (i.e. Low = ≤ −0.2, Medium = > −0.2 and <0, High = ≥ 0.) to facilitate MFE comparison despite negative standardized means.

3 | RESULTS

There was no significant difference in fishing effort between RCAs and unprotected sites (RCA – 0.17 MFE/half day, Unprotected – 0.2 MFE/half day). The RCA camera site with the highest fishing events (11 non-compliance events) was located at the north end of Active Pass just off Galiano Island (Figure 3). The unprotected camera site with the highest fishing effort (9 fishing events) was located at the south end of Active Pass. The four camera sites closest to Victoria showed no fishing effort. The model of ecological compliance influencers showed that fishing events were significantly correlated (P = <0.001, R^2 = 0.1) with sites that have a dominant depth range of 50–200 m. No other ecological predictors were significantly associated with fishing pressure (Table 2). The model of geographic compliance influencers showed RCA size was correlated with fishing effort (P = <0.001, R^2 = 0.03), with smaller RCAs experiencing higher levels of fishing effort (Table 2).

Seventy-nine percent of the RCAs monitored and 89% of reference sites showed either confirmed or probable fishing activity. The standardized MFE per month per RCA was not significantly different between 2011 and 2014. Four of the RCAs monitored had the same categorical ranking in both years, with low effort RCAs remaining the most consistent (Table 3).

Reference sites and RCAs both experienced the highest levels of fishing on weekends, with relatively consistent low levels of fishing throughout the rest of the week (Figure 4). Fishing effort was higher in reference sites than RCA sites on weekends. Percentage fishing effort by day varied slightly between RCA and reference sites, and fishing effort throughout the day (e.g. morning vs. evening) was nearly uniform across all site types.

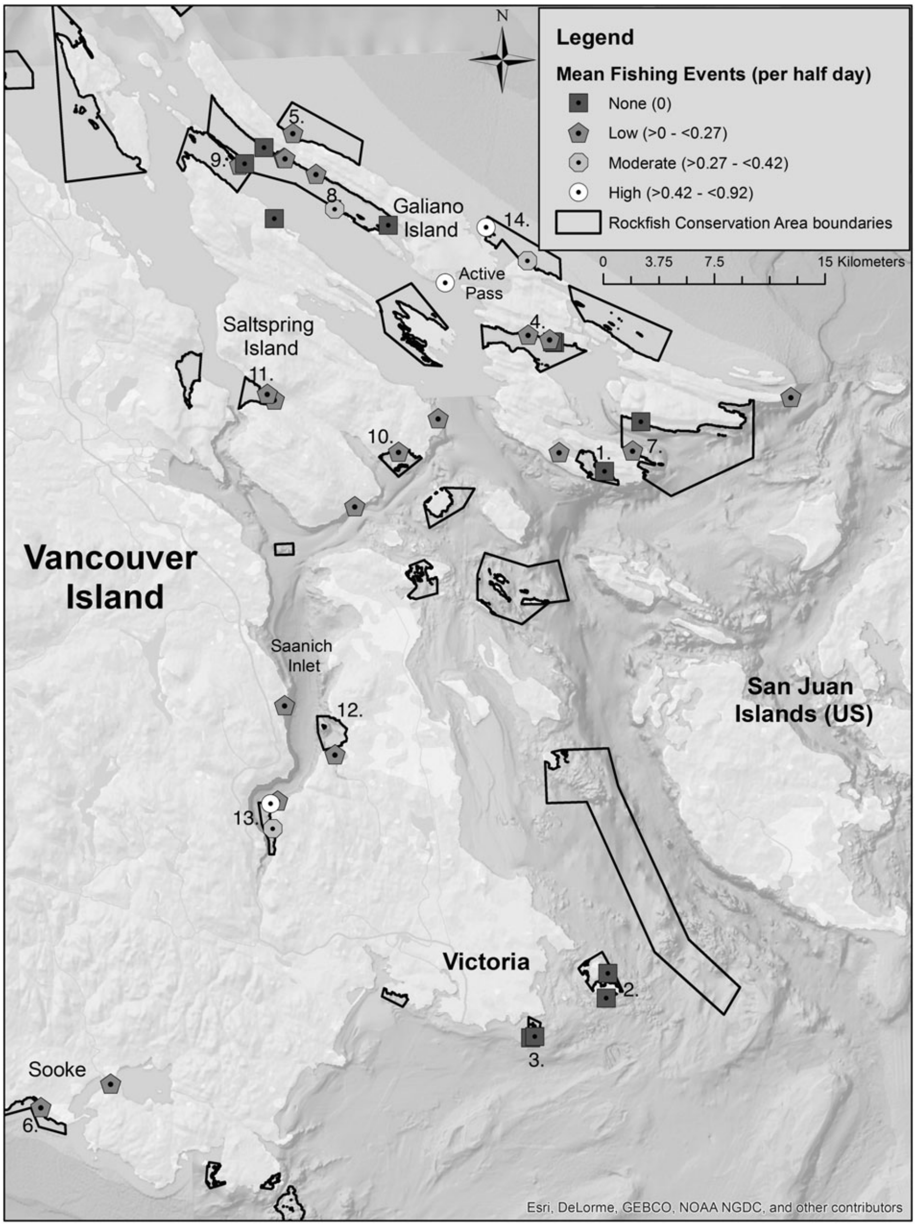

FIGURE 3 Gradient of mean fishing events at Rockfish Conservation Area (RCA; black outlines) and unprotected remote trail camera monitoring locations (July–August 2014) in the Salish Sea, British Columbia, Canada. Mean fishing events are ranked categorically from no fishing events (dark grey squares) to high fishing events (white circles). Numbers beside RCA locations correspond to numbers beside RCA names in Table 3

TABLE 2 Selection of GLMMs (Poisson distribution, log-link) of fishing effort at camera monitoring locations. Fishing effort was modelled against ecological predictor variables: rugosity, bottom type (Hard, Mud, Sand), depth levels (1 = 0–20 m, 2 = 20–50 m, 3 = 50–200 m, 4= > 200 m), bullkelp presence, and site type (RCA or unprotected). Fishing effort in RCAs was modelled against geographic predictor variables: RCA size and RCA perimeter to area ratios

	Model output (intercept + estimate*parameter...)	Marginal R^2	Conditional R^2	AIC
Full model (Ecological)	–2.85946 + 0.66123*Rugosity + –0.17150*Bottom type(level M) + 0.24907*Bottom type(level S) + 0.25058*Depth(level 2) + 1.02623*Depth(level 3) + –0.59455*Depth(level 4) + –0.08019*Bullkelp + –0.05587*Site type	0.12	0.30	447.6
Final model (Ecological)	–2.6574 + 1.5024*Depth(level 3)	0.10	0.26	436.7
Full model (Geographic)	–1.57431 + –0.04858*RCA size + –0.22529*Perm/Area Ratio	0.03	0.29	332.6
Final model (Geographic)	–1.956855 + –0.034717*RCA size	0.03	0.28	330.9

TABLE 3 Comparison of 2014 trail camera and 2011 aerial estimates of peak season (July–August) fishing activity by RCA. RCAs in bold have the same categorical ranking in both 2011 and 2014. The standardized effort was categorized according to the following scale: Low = ≤ −0.2, Medium = > −0.2 and <0, High = ≥ 0. Numbers beside RCA names correspond to numbers in Figure 3

	Trail Camera 2014				Aerial Survey 2011		
RCA name	Mean fishing events (per month)	Standardized mean	Rank	Category	Standardized mean	Rank	Category
1.Bedwell H.	0	-0.44	1	Low	-0.05	4	Medium
2.Discovery	**0**	**-0.44**	**1**	**Low**	**-0.32**	**1**	**Low**
3.Trial I.	**0**	**-0.44**	**1**	**Low**	**-0.32**	**1**	**Low**
4.Navy Ch.	**3.88**	**-0.28**	**2**	**Low**	**-0.32**	**1**	**Low**
5.Galiano N.	4.43	-0.26	3	Low	1.45	8	High
6.Sooke	5.17	-0.23	4	Low	-0.07	3	Medium
7.Saturna I.	5.91	-0.2	5	Medium	-0.32	1	Low
8.Trincomali	6.36	-0.18	6	Medium	0.04	5	High
9.Saltspring	6.64	-0.17	7	Medium	0.14	6	High
10.Russel I.	13.29	0.11	8	High	-0.32	1	Low
11.Burgoyne	14.31	0.15	9	High	-0.12	2	Medium
12.Brentwood	**16.91**	**0.26**	**10**	**High**	**0.68**	**7**	**High**
13.Finlayson	31	0.84	11	High	-0.32	1	Low
14.Mayne N.	41.33	1.26	12	High	-0.12	2	Medium

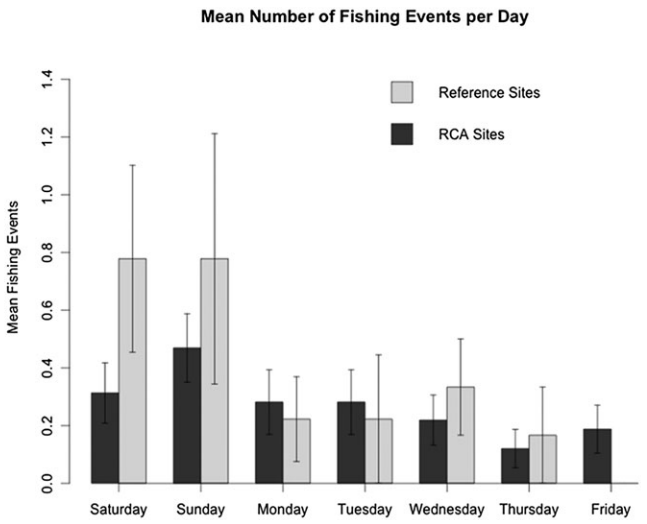

FIGURE 4 Mean number of recreational fishing events by day with standard error captured by shore based remote trail camera monitoring in Rockfish Conservation Area (RCA) and unprotected reference sites in the Salish Sea, British Columbia, Canada

4 | DISCUSSION

4.1 | Efficacy of shore-based camera monitoring

Shore-based camera monitoring was a reliable, efficient and cost-effective way of monitoring near-shore coastal marine conservation areas. Camera monitoring gave results comparable with aerial compliance data from Haggarty et al. (in press). Furthermore, camera monitoring may be more reliable for assessing area-specific fishing trends, because trail cameras operate from dawn to dusk, whereas fly-over data are a single temporal snapshot. Cameras can also be deployed and maintained year-round, enabling continuous data capture from minutes to seasons. Modest cost and ease of use make cameras a potential tool that local communities or non-government organizations can effectively employ (Greenberg & Godin, 2015). Camera monitoring is significantly less expensive and more time efficient than most other direct observation monitoring techniques, including shore-based observers (Ames & Schindler, 2009; Bergseth et al., 2013). Indeed, others have found that a related method, video monitoring, was more accurate than onshore observer monitoring and cut monitoring costs by nearly two-thirds, and analysis times by 75% (Ames & Schindler, 2009). Camera monitoring has the added benefit of faster analysis times and greatly superior battery life compared with video monitoring (Watson et al., 2015). However, information such as fishing entry and exit points and precise duration of fishing events cannot always be determined without video monitoring. Nevertheless, camera monitoring is an appealing option for small NGOs with limited funding interested in monitoring near-shore marine conservation areas. Developments in automated video and photo analysis software will continue to make these methods of monitoring more time and cost efficient.

Camera monitoring was generally comparable with aerial fly-over monitoring. Differences in some RCA rankings between years could be due to yearly variability, random stochasticity, changes in non-compliance rates at certain sites since 2011, or detection differences across methods. Although comparisons across methods and years is not ideal, the fact that there was no significant difference in fishing effort and no serious outliers suggests that fishing pressure and non-compliance rates have stayed relatively consistent during this period.

All compliance monitoring techniques come with challenges; however, camera and video monitoring offers the added benefit of capturing shore-based non-compliance that would typically be missed by aerial and boat-based survey methods (Greenberg & Godin, 2015; Watson et al., 2015). Three incidents of shore-based non-compliance were recorded during the study where individuals were seen shore-casting (a popular fishing method).

A limitation of camera monitoring is the relatively small FOV of each camera, the need to mount cameras on solid ground, and public concerns about surveillance. Camera monitoring is therefore most appropriate for near-shore, coastal marine conservation areas. Finding prime fishing monitoring locations that also minimize camera theft/damage can be a challenge. Cooperation of local park networks is helpful, and developing strong relationships with local area residents can facilitate access to well-situated private land, which often provides more camera security than public areas. Concerns about surveillance of fisher activities can be a sensitive topic, with many people uncomfortable with photographic monitoring (Watson et al., 2015). However, the growing popularity of surveillance technology (e.g. remote controlled drones) may make people more comfortable with such monitoring methods (Watson et al., 2015). Clear signs explaining the purpose of trail cameras and, when applicable, the ensured confidentiality of the collected data, along with contact information for lead researchers, may also alleviate concerns associated with camera monitoring. Further research on public perceptions of conservation surveillance and local recommendations should be an important part of designing camera monitoring networks.

The present study shows that trail camera monitoring can be an important tool for both researchers and managers. If paired with comprehensive ecological monitoring, camera monitoring could be a first step towards determining the cause of protected area success or failure. For example, if compliance is particularly low in a protected area with low or decreasing fish abundance in an otherwise healthy ecosystem, non-compliance may explain protected area failure. Furthermore, compliance information from trail camera monitoring can help to focus education and signage towards non-compliant 'hot spots'. Managers could also integrate trail camera monitoring into enforcement plans, which could allow enforcement officers to remotely monitor non-compliance and pinpoint popular non-complaint times and locations. If trail camera image resolution were improved, the possibility of prosecuting violators based on visible boat IDs, similar to roadside radar and red light cameras used by police, could also be considered. However, the practicality and legal and ethical implications of remote surveillance should be carefully considered.

4.2 | Compliance with rockfish conservation areas in BC

Our finding from trail camera monitoring that non-compliance in RCAs was widespread is corroborated from other sources. Nearly 80% of the RCAs monitored during this period experienced illegal fishing, and there was no significant difference in fishing effort inside vs. outside RCA boundaries. High levels of non-compliance in marine conservation areas are a serious problem, negating the ecological benefits of conservation (Edgar et al., 2014). Haggarty et al. (in press) found that >80% of RCAs showed fishing effort in 2007 and 2011 and, when compared with effort from 2003 before the RCAs were established, recreational fishing did not decline as a result of implementing the RCAs. Recent data from surveys with recreational fishers suggests that low knowledge of RCA rules and regulations are a major cause of RCA non-compliance: one-quarter of surveyed recreational fishers had never heard of RCAs, and 60% were not confident of RCA locations (Lancaster et al., 2015). Sixteen percent of fishers had accidentally fished within an RCA without knowledge of its protected status and 7% had intentionally fished in an RCA. Lancaster et al. (2015) and Haggarty (2015) suggest enhanced signage and education, increased monitoring to target intentionally non-compliant fishers, and the development of user-friendly software like mobile phone map applications to decrease intentional and accidental non-compliance.

Only one site with a dominant depth range greater than 200 m was sampled, so fisher preference inside and outside RCAs for sites with a dominant depth between 50 and 200 m likely suggests a preference for deeper sites overall. This preference for deep fishing sites may suggest targeted rockfish fishing since higher densities of rockfish are found at greater depth (Cloutier, 2011; Richards, 1986). However, Lancaster et al. (2015) found high accidental non-compliance by salmon and halibut fishers who also prefer deepwater sites. Furthermore, in 2011, DFO designated fishing areas that had higher rockfish catches did not have higher non-compliance rates (Haggarty et al., in press). Thus, much fishing effort within RCAs is probably accidental. However, fisher preference for deepwater sites may suggest high rates of fatal rockfish baurotrauma – which worsens with greater depth (Parker, McElderry, Rankin, & Hannah, 2006). Fisher-driven rockfish mortality in RCAs is likely to undermine the ability of these areas to rebuild rockfish stocks, especially in the heavily fished waters of the Salish Sea (Haggarty, 2015).

It is essential that education be implemented in tandem with increased monitoring to avoid drawing intentional poaching towards the RCAs. Increased awareness of RCAs without increased enforcement may create poaching hotspots if fishers believe the risk of penalty is low. These actions should be initiated by DFO, the regulatory agency, but NGOs can also play an important role in education and outreach, and initiating fisher-to-fisher, self-monitoring campaigns in the absence of sufficient DFO enforcement (Lancaster et al., 2015).

4.3 | Opportunities for future shore-based camera monitoring studies

Shore-based camera monitoring could be useful for a variety of future compliance monitoring studies. First, for projects aimed specifically at quantifying compliance within conservation areas, we suggest a similar research design with a focus on maximum coverage of conservation sites. Image analyser software developed for trail camera research should be used to streamline image analysis and minimize coding errors (Greenberg & Godin, 2015). Second, camera monitoring could be used to further study factors influencing compliance (e.g. environmental, geographic, social predictors) and to predict probable illegal fishing locations. Such studies should select even numbers of protected and unprotected sites, and control for habitat (e.g. depth, rugosity) and geographic variability (e.g. proximity to cities) in site selection. Monitoring periods should also be standardized as much as possible. A promising analysis would be to adapt occupancy modelling techniques, typically used for terrestrial mammals, to assess and predict fisher behaviour in coastal areas. Occupancy modelling for mammals uses knowledge of species habits and habitat preferences and deals with non-detection (Shannon, Lewis, & Gerber, 2014). Fishers targeting different species (e.g. salmon, halibut, rockfish) also target different habitats and use different fishing methods and, as such, occupancy modelling designs could be useful for creating focused fisher behaviour studies. Third, camera monitoring could be used to quantify the impact of education campaigns by measuring non-compliance in areas before and after an outreach initiative. A pilot study of this application is currently being tested by the Galiano Conservancy Association.

ACKNOWLEDGEMENTS

Funding provided by SSHRC, the Sara Spencer Foundation, the University of Victoria School of Environmental Studies, and Port Metro Vancouver. The authors thank BC Parks, SIMRES, and the Galiano Conservancy Association for fieldwork assistance and support and everyone who hosted trail cameras. Thanks also to J.T. Fisher for trail camera advice, to field research assistant K. Bryce, and to N. Shackelford and F. Stewart for data analysis assistance.

REFERENCES

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *19*, 716–723.

Ames, R. T., & Schindler, E. (2009). II Video monitoring of ocean recreational fishing effort. Oregon Department of Fish and Wildlife, Fish Division.

Ardron, J. A., & Wallace, S. (2015). Modelling inshore rockfish habitat in British Columbia: A pilot study. *Research Gate*. Retrieved from https://www.researchgate.net/publication/265488762 (accessed 20 February 2015).

Arias, A. (2015). Understanding and managing compliance in the nature conservation context. *Journal of Environmental Management*, *153*, 134–143.

Arias, A., & Sutton, S. G. (2013). Understanding recreational fisher compliance with no-take zones in the Great Barrier Reef Marine Park. *Ecology and Society*, *18*(4), 18.

Bates, D., Maechler, M., & Bolker, B. (2014). Linear mixed-effects models using Eigen and S4. Retrieved from http://CRAN.R-project.org/package=lme4 (accessed 7 March 2015).

BCMCA. (2015). British Columbia Marine Conservation Analysis: Maps, data, and reports. BC Conservation Foundation. Retrieved from http://bcmca.ca/maps-data/overview/.

Bell, S. (1997). *Ball and Bell on environmental law: The law and policy relating to the protection of the environment* (4th revised ed.). Oxford, UK: Blackstone Press Ltd. Retrieved from http://search.proquest.com/openview/d5178ccf7295c8a725b7226772580ada/1?pq-origsite=gscholar (accessed 29 May 2015).

Bergseth, B. J., Russ, G. R., & Cinner, J. E. (2013). Measuring and monitoring compliance in no-take marine reserves. *Fish and Fisheries*, *16*, 240–258.

Cloutier, R. N. (2011). Direct and indirect effects of marine protection: Rockfish conservation areas as a case study. Master's thesis, Simon Fraser University, Department of Biology.

Cook, R. M., Sinclair, A., & Stefansson, G. (1997). Potential collapse of North Sea cod stocks. *Nature*, *385*, 521–522.

Cooke, S. J., & Cowx, I. G. (2004). The role of recreational fishing in global fish crises. *Bioscience*, *54*, 857–859.

COSEWIC (2009a). *COSEWIC assessment and status report on the Yelloweye rockfish, Sebastes ruberrimus: Pacific Ocean inside waters population, Pacific Ocean outside waters population in Canada*. Ottawa: Committee on the Status of Endangered Wildlife in Canada.

COSEWIC. (2009b). COSEWIC assessment and status report on the Quillback Rockfish *Sebastes maliger* in Canada. Committee on the Status of Endangered Wildlife in Canada.

Cudney-Bueno, R., & Basurto, X. (2009). Lack of cross-scale linkages reduces robustness of community-based fisheries management. *PloS ONE*, *4*, e6253.

Daw, T. M., Cinner, J. E., McClanahan, T. R., Graham, N. A. J., & Wilson, S. K. (2011). Design factors and socioeconomic variables associated with ecological responses to fishery closures in the Western Indian Ocean. *Coastal Management*, *39*, 412–424.

DFO. (2012). Stock assessment for the inside population of yelloweye rockfish (*Sebastes ruberrimus*) in Britsh Columbia, Canada for 2010. Fisheries and Oceans Canada. Retrieved from http://www.dfo-mpo.gc.ca/Library/346394.pdf (accessed 21 January 2014).

DFO. (2014). *Rockfish Conservation Areas (RCAs) - Pacific Region*. Fisheries and Oceans Canada. Retrieved from http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/rca-acs/index-eng.html (accessed 3 February 2015).

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., … Thomson, R. J. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature*, *506*, 216–220.

Gelman, A., & Su, Y. (2015). arm: Data analysis using regression and multilevel/hierarchical models. R package version 1.8–5. Retrieved from http://CRAN.R-project.org/package=arm (accessed 2 April 2015).

Graham, N. A. J., Ainsworth, T. D., Baird, A. H., Ban, N. C., Bay, L. K., Cinner, J. E., … Williamson, D. H. (2011). From microbes to people: Tractable benefits of no-take areas for coral reefs. *Oceanography and Marine Biology: An Annual Review*, *49*, 105–136.

Greenberg, S., & Godin, T. (2015). A tool supporting the extraction of angling effort data from remote camera images. *Fisheries*, *40*, 276–287.

Haggarty, D. R. (2015). An evaluation of the effectiveness of Rockfish Conservation Areas in British Columbia, Canada. PhD dissertation, Zoology, University of British Columbia. Retrieved from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0216564 (accessed 5 February 2015).

Haggarty, D. R., Martell, S. J. D., & Shurin, J. B. (2016). Lack of recreational fishing compliance may compromise effectiveness of Rockfish Conservation Areas in British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences*, *73*, 1587–1598.

Lancaster, D., Dearden, P., & Ban, N. C. (2015). Drivers of recreational fisher compliance in temperate marine conservation areas: A study of Rockfish Conservation Areas in British Columbia, Canada. *Global Ecology and Conservation*, *4*, 645–657.

Little, L. R., Smith, A. D. M., Mcdonald, A. D., Punt, A. E., Mapstone, B. D., Pantus, F., & Davies, C. R. (2005). Effects of size and fragmentation of marine reserves and fisher infringement on the catch and biomass of coral trout, *Plectropomus leopardus*, on the Great Barrier Reef, Australia. *Fisheries Management and Ecology*, *12*, 177–188.

Love, M. S., Yoklavich, M., & Thorsteinson, L. K. (2002). *The rockfishes of the northeast Pacific*. Berkeley, CA: University of California Press.

Marinesque, S., Kaplan, D. M., & Rodwell, L. D. (2012). Global implementation of marine protected areas: Is the developing world being left behind? *Marine Policy*, *36*, 727–737.

Martin, T. G., Burgman, M. A., Fidler, F., Kuhnert, P. M., Low-Choy, S., McBride, M., & Mengersen, K. (2012). Eliciting expert knowledge in conservation science. *Conservation Biology*, *26*, 29–38.

Ministry of Sustainable Resource Management. (2002). British Columbia Marine Ecological Classification V2. Province of British Columbia. Retrieved from https://www.for.gov.bc.ca/hts/risc/pubs/coastal/marine/version%202/bcmec_version_2.pdf (accessed 10 March 2015).

Molfese, C., Beare, D., & Hall-Spencer, J. M. (2014). Overfishing and the replacement of demersal finfish by shellfish: An example from the English Channel. *PloS ONE*, *9*, e101506.

Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution*, *4*, 133–142.

Parker, S. J., Berkeley, S. A., Golden, J. T., Gunderson, D. R., Heifetz, J., Hixon, M. A., … Yoklavich, M. M. (2000). Management of Pacific rockfish. *Fisheries*, *25*(3), 22–30.

Parker, S. J., McElderry, H. I., Rankin, P. S., Hannah, R. W. (2006). Buoyancy regulation and barotrauma in two species of nearshore rockfish. *Transactions of the American Fisheries Society*, *135*, 1213–1223.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., … Zeller, D. (2002). Towards sustainability in world fisheries. *Nature*, *418*(6898), 689–695.

R Core Team. (2013). *R: A language and environment for statistical computing*. Vienna, Austria: Retrieved from http://www.R-project.org/R Foundation for Statistical Computing.

Richards, L. J. (1986). Depth and habitat distributions of three species of rockfish (*Sebastes*) in British Columbia: Observations from the submersible PISCES IV. *Environmental Biology of Fishes*, *17*, 13–21.

Robbins, W. D., Hisano, M., Connolly, S. R., & Choat, J. H. (2006). Ongoing collapse of coral-reef shark populations. *Current Biology*, *16*, 2314–2319.

SARA. (2014). Species at Risk Act: A Guide. Government of Canada. Retrieved from http://www.registrelep-sararegistry.gc.ca/default.asp?lang=Enandn=F3178B4D-1 (accessed 2 December 2014).

Shannon, G., Lewis, J. S., & Gerber, B. D. (2014). Recommended survey designs for occupancy modelling using motion-activated cameras: Insights from empirical wildlife data. *PeerJ*, *2*, e532.

Smallwood, C. B., & Beckley, L. E. (2012). Spatial distribution and zoning compliance of recreational fishing in Ningaloo Marine Park, north-western Australia. *Fisheries Research*, *125–126*, 40–50.

Watson, G. J., Murray, J. M., Schaefer, M., & Bonner, A. (2015). Successful local marine conservation requires appropriate educational methods and adequate enforcement. *Marine Policy*, *52*, 59–67.

Williamson, D. H., Ceccarelli, D. M., Evans, R. D., Hill, J. K., & Russ, G. R. (2014). Derelict fishing line provides a useful proxy for estimating levels of non-compliance with no-take marine reserves. *PloS One*, *9*, e114395.

Yamanaka, K. L., & Logan, G. (2010). Developing British Columbia's inshore rockfish conservation strategy. *Marine and Coastal Fisheries*, *2*(1), 28–46.

Yamanaka, K. L., Lacko, L. C., & Secretariat, C. S. A. (2001). *Inshore rockfish stock assessment for the west coast of Canada and recommendations for management*. *Fisheries and Oceans Canada*. Ottawa: Canadian Science Advisory Secretariat.

Zetterberg, P. R., Watson, N. M., & O'Brien, D. S. 2010. Strait of Georgia Recreational Fishery Statistics for Salmon and Groundfish, 2008. Canadian Manuscript Report of Fisheries and Aquatic Sciences.

How to cite this article: Lancaster D, Dearden P, Haggarty DR, Volpe JP, Ban NC. Effectiveness of shore-based remote camera monitoring for quantifying recreational fisher compliance in marine conservation areas. *Aquatic Conserv: Mar Freshw Ecosyst*. 2017;27:804–813. https://doi.org/10.1002/aqc.2736