Biological Conservation 219 (2018) 138–146

Contents lists available at ScienceDirect

Biological Conservation

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

Community assembly and the sustainability of habitat offsetting targets in the first compensation lake in the oil sands region in Alberta, Canada

Jonathan L.W. Ruppert[a,*], Joanne Hogg[b], Mark S. Poesch[a]

[a] University of Alberta, Department of Renewable Resources, 751 General Services Building, Edmonton, AB T6G 2H1, Canada
[b] Canadian Natural Resources Limited, 855-2nd St. SW, Calgary, AB T2P 4J8, Canada

ARTICLE INFO

Keywords:
Resilience
Community concordance
Meso-predator release
Trophic structure
Conservation management
System connectivity

ABSTRACT

Resource development can have a negative impact on species productivity and diversity through the loss and fragmentation of habitat. In many countries, developers are required by law to offset such impacts by replacing lost habitat or providing other forms of compensation. In the case of broad scale development, offsets often cannot be constructed to replace lost habitat "like-for-like" (i.e., they are not ecologically equivalent). In freshwater ecosystems, one approach to habitat offsetting is to create new lake ecosystems, called compensation lakes, to replace lost riverine habitat. In this study, we use a long-term data set (2008–2015) of fish and benthic invertebrate communities from Canada's first compensation lake in the oil sands region of Alberta, to address (1) whether the assembly of the fish community has a trajectory that is influenced by management activities and (2) determine whether the community composition in the habitat offset is common in natural lake ecosystems within the region. We find a significant decline in the mean trophic level of the lake, where 61.9% of the variation in trophic level is explained by time indicating a strong structuring influence on fish communities. This outcome has enabled the compensation lake to meet overall and single species productivity targets, but we find that the species assemblage and composition is not common within the region. A combination of the founding species community and reduced connectivity of the lake has contributed to the current fish community structure, which may be problematic for the sustainability of the habitat offsetting targets. Our study highlights the need to establish multiple conservation guidelines, using both productivity and diversity based metrics, to provide the best ecological equivalency, which can produce better function, resilience and health within focal species communities in habitat offsets that are not "like-for-like."

1. Introduction

Globally, one of the major drivers of declines in the productivity and biodiversity of species, and their habitats, is through land-use change (Dirzo et al., 2014; Sala et al., 2000). One form of land-use change that can cause such habitat loss is resource development (Bull et al., 2013; Minns, 2015). When the avoidance, minimization, and mitigation of this impact is not possible, habitat offsets may provide a solution to achieve no net loss of a particular targeted habitat feature (BBOP, 2012; IFC, 2012). Many countries have adopted habitat offsetting policies (e.g., Canada, United States, Europe, Australia, New Zealand, and United Kingdom), where the ideal goal is ecological equivalency, such that offsets are done in a manner which replaces habitats "like-for-like" in areas in close proximity to where those habitats were displaced (Bull et al., 2015; Bull et al., 2013). When ecological equivalency cannot be achieved with habitat offsets, such as when the extent, duration and intensity of the impacts are sufficiently broad in spatio-temporal scale (e.g., surface mining, urban development), new offsetting currencies and flexibility may be needed (Bull et al., 2015; Habib et al., 2013).

Underpinning the management goal to maintain productivity and biodiversity in habitat offsetting practices are the many ecological processes supported by species assemblages and community structure, which will provide desirable levels of resilience, function and health in ecosystems (Bull et al., 2015; Bull et al., 2013; DeFries and Nagendra, 2017). Of note, higher species diversity can generate increased functional diversity (Tilman et al., 1997), which in turn provides communities with a set of species that have differential responses to environmental variability (McCann, 2000). Thus, one might expect that comparable ecosystem resilience and function would result from maintaining biodiversity in habitat offsets (Dudgeon et al., 2006; Folke et al., 2004; Vander Zanden et al., 2006). Moreover, the goal of habitat offsets is to emulate natural ecosystem processes, which will require comparable species diversity to what is lost to development (Bull et al., 2013). A major difficulty in achieving this outcome is that successional

* Corresponding author.
E-mail addresses: jruppert@ualberta.ca (J.L.W. Ruppert), Joanne.Hogg@cnrl.com (J. Hogg), poesch@ualberta.ca (M.S. Poesch).

https://doi.org/10.1016/j.biocon.2018.01.014
Received 13 January 2017; Received in revised form 8 December 2017; Accepted 12 January 2018
Available online 03 February 2018

or community assembly processes in many new ecosystems is not well resolved with many taxa (Palmer et al., 1997). In order to reduce this uncertainty, single species management approaches may be preferred (where interactions may be better resolved and there is greater certainty); however, there is the danger that this may contribute to lower functional diversity, which could increase variability in the ecosystem (e.g., fisheries productivity), preventing the establishment of a resilient and functioning ecosystem (DeFries and Nagendra, 2017; Lambeck, 1997).

In Canada, companies are required by law to develop offsetting strategies to compensate for fish habitat loss in aquatic ecosystems (Minns, 2006, 2015; Rice et al., 2015). Specifically, the current policy states that the creation of habitat offsets is required when unavoidable serious harm to fish or losses in Commercial, Recreational and Aboriginal (CRA) fisheries productivity occurs (Rice et al., 2015). Thus, the offsetting currency is CRA fisheries productivity (which can be simply defined as $kg{\cdot}yr^{-1}$) that is supported by compensating for fish habitat loss. Moreover, the CRA fisheries productivity is defined as losses to a specific fishery and the fish species that support that fishery, which broadly includes all fish species within the ecosystem (DFO, 2013, 2014). To offset the loss of fish habitat that is originally in lotic and lentic freshwater ecosystems the construction of new lake ecosystems, hereafter referred to as compensation lakes, is gaining interest. In the oil sands region in northern Alberta, which represents the third largest oil reserves in the world, industrial activities have been increasing dramatically within the past couple decades, which has led to an increased footprint, or impact, on aquatic ecosystems (Schwalb et al., 2015; Webster et al., 2015). In response, there has been a subsequent initiation of many compensation lake projects within the region (five constructed lakes and five or more are currently within the planning process; Court Berryman, Department of Fisheries and Oceans, Edmonton, Alberta, *personal communication*, 2016), making it one of the most active areas in Canada within the scope of habitat offsetting via compensation lakes (see Fig. 1A). Fish communities in the oil sands region, which is in the lower Athabasca watershed, are not speciose or highly productive ecosystems (Nelson and Paetz, 1992). However, despite the apparent simplicity in terms of fish diversity, there is still much uncertainty related to processes that can alter the establishment and trajectory of the resulting fish community and ecosystem (DeFries and Nagendra, 2017; Matthews and Marsh-Matthews, 2016).

Much uncertainty remains within the management framework of offsetting practices, including: the assembly and stocking of fish communities, the long-term sustainability of management targets, identifying the importance of the role and sequence of structuring processes, establishing an appropriate baseline or reference system, among many others aspects (Minns, 2015; Vander Zanden et al., 2006). Specifically, the assembly of fish communities may include stochastic (e.g., priority effects, drift) and deterministic (e.g., competition, predator-prey relationships, connectivity) processes that can shape the resulting state of a community and ultimately the ecosystem (Carpenter et al., 2001; Matthews and Marsh-Matthews, 2016; Milner et al., 2011; Vander Zanden et al., 2006; Webster et al., 2015). For instance, the order of introduction (i.e., priority effects) and subsequent species interactions can play a major role in determining the outcome of fish communities and the resulting long-term productivity and/or diversity within the system (Matthews and Marsh-Matthews, 2006; Vander Zanden et al., 2006). Moreover, the benefits of balancing top-down and bottom-up control within the ecosystem cannot be overstated, where the establishment of predator-prey interactions early on in the assembly process can provide more stability and resilience in the composition of fish communities (Brashares et al., 2010; Carpenter et al., 2001; Estes et al., 2011). One way to assess the influence management has on community assembly is by using whole-ecosystem experiments to provide insight, where conservation management decisions can have impacts on ecosystem outcomes.

In this study, we investigate the initial assembly of the fish and benthic invertebrate communities using a long-term data set (2008–2015) from the first compensation lake established within the oil sands region of northern Alberta. Specifically, we address: (1) whether the assembly of the fish community has a trajectory that is influenced by management activities and (2) determine whether the community composition in the habitat offset is common in natural lake ecosystems within the region. Addressing these questions will help to outline the potential processes that govern fisheries productivity in compensation lake ecosystems during the first years following establishment. Moreover, we provide context on the contribution of management decisions during community assembly and assess whether productivity focused management objectives maximize ecological equivalency to achieve long-term sustainability of the fishery and ecosystem.

2. Methods

2.1. Study area

Horizon Lake is a compensation lake, which was established along the Tar River within the lower Athabasca watershed in 2008 (Fig. 1). The compensation lake was created to offset the loss of lotic fish habitat that previously existed prior to mining operations (see light grey polygon in Fig. 1). Horizon Lake has a surface area of approximately 77 ha, with an average depth of 7.2 m and a maximum depth of about 23 m (Jiang et al., 2015). The design of the compensation lake included the establishment of deep channels, shoals, and multiple substrates including sand, cobble and gravel to promote habitat heterogeneity and fisheries productivity. While the initial design was based on promoting overall fisheries productivity (i.e., multiple species), there is also a desire to promote Arctic Grayling (*Thymallus arcticus*) productivity. Thus, the colonization of several species (namely higher trophic level species) has not been facilitated in order to assess potential Arctic Grayling productivity within the compensation lake. The potential shift in focus reflects a need to promote Arctic Grayling productivity within Alberta, as they are experiencing population declines and range recession within the province (ASRD, 2005). Horizon Lake has a major inflow (Upper Tar River) and outflow (Lower Tar River), where fish may freely move upstream, however, they are prevented from moving downstream due to the presence of a screen on a submerged outlet. The long-term management plan (30+ years) is to reconnect Horizon Lake to the Athabasca watershed. Water residence time in Horizon Lake can be a few weeks to months depending on whether it is wet or dry season and the lake is covered by ice from mid-November to early May. The hydrodynamics of Horizon Lake have been studied in detail by Jiang et al. (2015).

2.2. Fish and benthic invertebrate sampling

Fish and benthic invertebrate communities in Horizon Lake have largely colonized from the Upper Tar River, with the exception of 4749 Fathead minnows (*Pimephales promelas*) and 1630 Brook sticklebacks (*Culaea inconstans*) that were released into Horizon Lake from a nearby lake (Calumet Lake) in 2009 (Fig. 1). We used historical data records spanning 2008–2015, where sampling for fish and benthic invertebrates commenced immediately after the establishment of Horizon Lake in the fall of 2008 and occurred semi-regularly depending on the location and type of sampling (e.g., fish vs. invertebrates; Table S1). The most consistent sampling occurred annually during the fall season (Table S1). Fish were collected using standardized Fall Walleye Index Netting (FWIN), which consists of a gill net of 8 panels of differing mesh sizes (1, 1.5, 2, 2.5, 3, 4, 5, and 6 in.), where each panel is 1.8 m wide and 7.6 m long, making the full length of the net 60.8 m. FWIN netting is the standard sampling protocol used by the province of Alberta (AEP, 2015) as well as elsewhere (Morgan, 2002) to determine fish community composition. Sampling was conducted in at least 3 or 4 locations (some times more) in 1–3 seasons per year and repeated for several days at a