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Describing growth based on landscape characteristics and stocking strategies for rainbow trout

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ABSTRACT

The achievement of target growth rates of stocked fish in a particular environment is an important component of recreational fisheries management; if stocked fish do not achieve a desired size structure, then angling effort and satisfaction may be lower than anticipated. We developed a growth model for rainbow trout (*Oncorhynchus mykiss*) based on a Bayesian hierarchical analysis of growth data from 142 gillnet assessments across the province of British Columbia. The growth equation was defined as a von Bertalanffy function with environmental and stocking covariates applied to the function's asymptotic length (L_∞) and metabolic rate (K) parameters. Key factors defining growth for the best performing model were the time spent in lake based on accumulated growing degree days, the life-stage at stocking, stocking density, and the stocked strain. Calculating time in-lake in terms of growing degree days experienced by fish instead of calendar days in-lake improved the prediction of growth. We explore examples of how to use this information, such as identifying stocking rates needed to achieve particular size thresholds given size-structure objectives for a stocked lake fishery. This analysis helps managers determine how to efficiently distribute hatchery-reared fish across the landscape and recognize limits to growth given particular environmental constraints while also tailoring to the diversity of angler preferences and expectations of the fishery.

1. Introduction

Fish size and catch rates are two of the primary catch-related motivations driving decisions on whether and where an angler will fish (Dabrowksa et al., 2017). Growth in many stocked freshwater species, is "inherently plastic" (Lorenzen, 2016) and affected by a broad suite of biotic and abiotic factors (van Poorten and Walters, 2016). Recreational anglers vary in the types of fisheries experiences sought (Aas and Ditton, 1998; Hunt et al., 2013; Parkinson et al., 2004); the success of stocking programs depends on the ability to reliably provide a variety of population size structures on lakes across the landscape to meet the needs of a diverse angling community (Johnston et al., 2010). Despite the importance of factors that lead to variation in growth rates, stocking policies often do not explicitly consider quantitative predictions of growth potential that may be attainable with particular stocking densities in particular environmental conditions. Although experiential models and rules of thumb for growth potential in particular lakes may exist for many managers, quantitative models may allow stocking decisions to be better communicated among managers and stakeholders and improve overall fishery performance.

Gillnetting-based sampling methods have commonly been adopted by North American biologists to assess fish populations in smaller lakes (Willis, 1987; Appelberg, 2000; Ward et al., 2012). Gillnet assessment data are usually used to monitor the performance of the fisheries on a lake-by-lake basis, yet these data provide an opportunity to explore landscape-level patterns in growth variation that would not be possible experimentally. These data integrate growth information over a broad suite of lakes across a large geographic area, providing much greater contrast in environmental and demographic data than would be possible in time-series data on a single lake (e.g. He and Stewart, 2002; He

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and Bence, 2007). Further, stocked lakes offer contrasts in initial fish density for exploring density dependent effects on fish growth. Combining data from multiple assessment datasets over many populations provides a unique opportunity to explore growth, productivity, and density trade-offs across the landscape (Helser and Lai, 2004).

Growth is an important biological process, which is influenced by energy surplus. Factors that influence consumption (anabolism) or metabolism (catabolism), or both govern growth plasticity (van Poorten and Walters, 2016). In stocked lake fisheries, average individual food consumption by fish can be limited by competition with conspecifics (Walters and Post, 1993; Post et al., 1999). Likewise, environmental conditions can have variable impacts on growth through direct impacts on metabolism and indirect impacts on consumption (through availability of prey) (Boisclair and Sirois, 1993; Hewett and Kraft, 1993). The extent of these effects may be determined by a combination of life history and environment; for example, Askey et al. (2013) showed that environmental conditions, primarily growing season length determine the magnitude of the density effect. When considering growth potential for fish in any given environment, each of these factors should be considered with respect to their impact on consumption and metabolism.

We estimate the relative influence of various biotic and abiotic factors on growth of rainbow trout populations distributed over a large number of stocked British Columbia lakes. We utilize standard sampling data gathered over multiple years, taking advantage of a broad suite of environmental conditions and stocking densities. We develop multiple models and evaluate their performance based on three criteria: (i) parsimony, (ii) model fit perspectives, and (iii) ability to predict out-of-sample data. The results of the best performing model are used to calculate expected stocking densities across the British Columbia landscape to achieve a variety of size-based management objectives.

2. Methods

2.1. Study system and data collection

British Columbia (BC) is a large jurisdiction for recreational fisheries management: this includes approximately 20,000 angling lakes that support a clientele of 350,000 licensed anglers (FFSBC, 2011). Approximately 675 small lakes, generally between 100 and 1000 ha, are annually stocked (FFSBC, 2015) with rainbow trout (*Oncorhynchus mykiss*) and more than half of the total angling effort on small lakes is concentrated on these stocked populations (Gislason et al., 2009). Though lakes < 1000 ha are stocked, the majority of the stocked lakes are smaller than 100 ha. A large proportion of the stocked lakes are those which are not connected to other waterbodies via inlet or outlet streams. Most of these lakes are only stocked with Rainbow trout and are essentially monoculture lakes maintained for the purpose of recreational fishing. Though there are stocked lakes that have natural recruitment, in the majority of cases, fish density is determined by stocking densities. Survival of Rainbow trout is understood to be higher in monoculture lakes compared to lakes with other species on account of competition for food resources and predation on young stocked fry.

Stocked lakes cover a large portion of southern BC (Fig. 1). Lakes range in elevation from 0 to 2000 masl and range from a latitude of 48.3 to 58.5 °N. The productivity of BC lakes is known to vary considerably between inland and coastal regions; coastal lakes have higher flush rates and lower productivity while inland lakes with lower flush rates have higher productivity (Ashley and Nordin, 1999). Lakes in the south of the province have a longer growing season (> 1000 growing degree days calculated above base temperature of 5 °C; GDD) compared to lakes in the north (< 1000 GDD).

Rainbow trout stocked in BC small lakes are predominantly either 'fry' or 'yearling' from one of several strains. Fry are stocked in the fall (September–October) at age-0+; yearlings are stocked in summer (May–June) at age-1. Yearlings are larger in size and stocking densities are generally lower than for fry. Rainbow trout strains included in the analysis are 'Pennask', 'Blackwater', 'Tzenzaicut', 'Carp Lake', 'Fraser Valley domestic', 'Gerrard', and mixed strain stockings. All strains hatch in spring except for the domestic, 'Fraser Valley' strain. Fraser Valley strain hatch in late fall and are stocked in spring; hence, their age in-lake is approximately half a year younger than their wild-strain counterparts. Each strain is defined as having unique feeding, aggression and competitive characteristics (Pollard and Yesaki, 2008; Northrup and Godin, 2009). Blackwater and Tzenzaicut strains of rainbow trout were aggregated in our analysis because of similarity in behavior and because they are often stocked together. Sterile (triploid) fish are also stocked in some lakes to produce higher condition fish and/or preserve the genetic diversity of native stocks.

Fisheries managers have assigned stocked lakes into one of four fishing categories: Trophy (low density, large body size), Urban (high density catchable), Family (high density, low body size) or Regional (average density and body size). The sets of fishery attributes provided by these lake categories have been formed to match findings about angler preferences in the province (Dabrowksa et al., 2017). Decisions about stocking densities and strains are made on a lake-by-lake basis with respect to these categories. Stocked fish become vulnerable to fishing at sizes 22 cm and higher which roughly corresponds to fish age 2 and higher (Askey et al., 2013). Because of the trade-off between growth and survival, size structure and abundance is quite variable, providing a range of fish size and catch rates across lakes. Lake categories 'Urban' and 'Family' tend to provide fisheries with high catch rates but smaller average fish sizes (ages 2–3). Urban lakes are located close to population centres, are generally smaller than 20 ha, and are stocked at high densities of age-2 'catchable' fish. Lake category 'Trophy' cater to specialized anglers targeting large fish (ages 3, 4, and 5); these lakes generally tend to have several restrictions on harvest, for example catch and release or one fish over 50 cm allowed to be harvested. Trophy lakes tend to be located far from large urban centres, have the lowest stocking densities among the different lake categories and must be productive enough to achieve fish of larger size. Regional lakes provide a fishery where fish sizes are generally higher than in 'Family' lakes and the catch rates and opportunities to keep the fish are expected to be higher than in 'Trophy' lakes. Biologists take into account the environmental attributes (e.g., pH, shoal area, growing degree days, flushing rate) of each lake with the aim of achieving objectives for fish sizes and densities and fishing experiences that are associated with the lake's fishing category.

Between 60 and 100 stocked lakes are surveyed each autumn with a standardized gill-net configuration (Ward et al., 2012) to assess rainbow trout density and size structure. Surveys are conducted using one pelagic and one benthic gang of gillnets according to standard protocol consisting of seven panels of varying size arranged in a fixed order (25, 76, 51, 38, 89, 64 and 32 mm) attached at the top and bottom of the net. Nets are set overnight in each lake to improve catching efficiency from crepuscular fish activity. Captured fish are identified to species, measured for length, examined for tags or fin clips (which may have been used at stocking to identify age-class or strain) and have scales or otoliths removed for aging.

The BC Small Lakes Database has data from 1070 gillnet assessments across many years and lakes. Of these, 632 assessments have paired data on lengths and ages. For this analysis, individual lake assessments were removed when: (1) multiple age-classes were stocked in the same year which obscured records of time in-lake; (2) covariate information on stocking density, strain, ploidy or total dissolved solids were unavailable; and (3) fewer than three age-classes or fewer than 20 fish over age-1 were captured. These criteria reduced the total data to 142 assessments from 91 lakes, which were used for the analyses. The assessments used in the analysis extended over much of the distribution of stocked rainbow trout in the province (Fig. 1). Assessments that did not satisfy criterion 3 but satisfied all other criteria were used to assess out-of-sample model prediction.