DOI: 10.1111/fme.12208

ORIGINAL ARTICLE

WILEY Fisheries Management and Ecology

Modelling and management options for salmonid sport fisheries: A case study from Patagonia, Argentina

M. Rechencq[1,2] | **P. H. Vigliano**[1,2] | **G. E. Lippolt**[1] | **M. F. Alonso**[1] | **P. J. Macchi**[1,2] | **P. A. Alvear**[2] | **V. Hougham**[1] | **M. A. Denegri**[1,2] | **G. Blasetti**[4] | **R. Juncos**[3] | **M. V. Fernandez**[1] | **M. E. Lallement**[1,2] | **S. M. Juarez**[1,2]

[1]Grupo de Evaluación y Manejo de Recursos Ícticos (GEMaRI), Centro Regional Universitario Bariloche (CRUB) – Universidad Nacional del Comahue (UNCo), Bariloche, Río Negro, Argentina

[2]Instituto de Investigaciones en Biodiversidad y Medio Ambiente (INIBIOMA), Universidad Nacional del Comahue (UNCo) – Centro Científico Tecnológico Patagonia Norte, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Bariloche, Río Negro, Argentina

[3]Laboratorio de Análisis por Activación Neutrónica, Centro Atómico Bariloche (CAB) – Centro Científico Tecnológico Patagonia Norte – Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Bariloche, Río Negro, Argentina

[4]Autoridad Interjurisdiccional de las Cuencas de los ríos Limay, Neuquén y Negro (AIC), Cipolletti, Río Negro, Argentina

Correspondence
Magalí Rechencq, Grupo de Evaluación y Manejo de Recursos Ícticos (GEMaRI), Centro Regional Universitario Bariloche (CRUB) – Universidad Nacional del Comahue (UNCo), Bariloche, Río Negro, Argentina.
Email: magalirechencq@gmail.com

Funding information
Autoridad Interjurisdiccional de Cuencas de los Ríos Limay, Neuquén y Negro; Universidad Nacional del Comahue CRUB, Grant/Award Number: UNCO B025.

Abstract

Salmonid sport fishery management in Argentinian Patagonia is usually guided by stakeholder perceptions, which do not consider the biological and ecological constraints acting upon aquatic resources. An example of this are management policies for Traful Lake, where Atlantic salmon, *Salmo salar* L., was actively stocked during the last decade in an attempt to change the fish assemblage structure and to create a highly valuable sport fishery. This study assesses the likelihood of these policies achieving such assemblage structure changes through the study of affluent-stream suitability as spawning and breeding grounds, lake fish assemblage parameters, trophic diversity and possible competition due to diet overlap. This study also assesses alternative management practices through population simulations and bioenergetic modelling under diverse catch-size limit scenarios. This study concludes that it is not advisable to try to generate a unique and distinctive sport fishery by stocking Atlantic salmon in an already renowned fishery in Northern Patagonia. Instead, a more comprehensive framework for decision-making is suggested, involving short-term studies that go beyond the specific problem of the target species and incorporate the whole fish assemblage using diverse approaches and modelling strategies.

KEYWORDS
bioenergetic models, dynamic pool, fishery, management, Patagonian salmonids, yield per recruit

1 | INTRODUCTION

Fisheries science and management-related studies around the world have gradually become context-oriented, taking into consideration multiple spatial, temporal, biological and sociological factors. Thus, management has evolved from being exclusively target-species-oriented and now it is influenced by constraints imposed by abiotic factors of the environment, interrelationships between different fish species, ecological capability of ecosystems, and interests and pressures exerted by stakeholders (Cowx, 2000; Kohler & Hubert, 1999). Since the first introduction of salmonid fishes into Argentinian Patagonia in 1904, a series of renowned world-class sport fisheries have been developed in the region and have been historically managed mainly based on fisher's perceptions (Pascual et al., 2007; Vigliano & Alonso, 2007). An overview of freshwater fish science in Patagonia pointed out the lack of context-oriented strategic planning

© 2017 John Wiley & Sons Ltd

and policies as one of its major problems (Macchi & Vigliano, 2014; Macchi et al., 2008; Pascual et al., 2007). Thus, management actions have usually been tailored to respond to specific urgent problems or perceptions of different interest groups, with little or no consideration of the biophysical constraints inherent to aquatic ecosystems. Part of this problem stems from the lack of necessary expertise among local or regional administrators, who have implemented management strategies based on biased perceptions or political interests.

A good example is Traful Lake in Northern Patagonia, which sustains a sport fishery based on a feral salmonid community, which is locally important due to the size and health of their fish (Vigliano et al., 2008). Fishers usually catch abundant rainbow trout, *Oncorhynchus mykiss* (Walbaum), brown trout, *Salmo trutta* (Linnaeus), and brook trout, *Salvelinus fontinalis* (Mitchill), species found in most other Argentine Patagonian lakes. What sets Traful Lake apart is the low numbers of Atlantic salmon, *Salmo salar* (Linnaeus), which are absent from most lakes in the region, and thus offers fishers a rare opportunity to catch this species. To capitalise on this unique feature and encourage the local economy through the generation of a distinctive sport fishery based on a target species scarce in the region, provincial authorities were advised by a local research agency to increase fishing mortality of rainbow trout and boost the numbers of Atlantic salmon by stocking 10,000 specimens per year, with the aim of shifting fish assemblage dominance from trout to salmon (CEAN 2002).

A preliminary evaluation of the lake's fish resource showed that it was unlikely that such a replacement strategy would be successful. Furthermore, a roving creel census suggested that fishers were satisfied with the current fishing quality and had no preference for Atlantic salmon (Vigliano et al., 2002). While this resulted in stalling the proposed management actions, Atlantic salmon was nonetheless stocked off the record between 2002 and 2005. In 2006, fishers complained that Atlantic salmon numbers remained low, and that stocking had apparently failed to establish spawning runs on the lake's numerous tributaries. This prompted a series of workshops involving all interested parties, during which some participants attributed the failure of Atlantic salmon stocking to competition for food resources with rainbow trout, reiterating their perception that stocking, while jointly increasing the rainbow trout kill quota, would generate a distinctive Patagonian fishery. The workshops also underlined the lack of basic information and understanding of the key processes that could be structuring the lake's fish assemblage. Most relevant among these were the suitability of tributaries as spawning and breeding grounds for salmonids, the actual composition and structure of the lake's fish assemblage and its populations (species, sizes, ages, and abundances), and the interrelationships among fish species, their trophic diversity and possible competition for food resources. In addition, it became evident that neither fishing guides nor local authorities had considered the potential negative impacts of their favoured strategy. Adequate management of the lake's fish resource requires the evaluation of different scenarios that consider fish assemblage processes, biological constraints and potential drawbacks. All interested parties must be made fully aware of these processes and possible outcomes of proposed management actions. This study presents a case in which the parties seem to hold an incomplete understanding of ecosystem management and abide by misguiding management policies. It also examines ways in which these negative effects can be minimised by addressing a series of biological issues necessary to detect potentially critical problems of such policies and then using yield per recruit, dynamic pool and bioenergetic models to simulate the possible outcomes of alternative management strategies under diverse scenarios.

Objectives were to: (1) generate lake-wide baseline information regarding year-round fish assemblage structure and population parameters; (2) analyse stream tributaries suitability and importance as salmonid spawning and breading habitats on the structuring of the lakes fish assemblages; (3) establish baseline conditions in terms of species composition, abundance patterns and population structures and parameters for the lake's fish assemblage; (4) use year-round samplings to determine possible dietary overlaps and thus potential competition processes among fish species; (5) use bioenergetics modelling to determine how consumption specific to salmonid species impacts on the different prey items; (6) characterise the current quality of the sport fishery and analyse the feasibility of reducing rainbow trout numbers through sport fishing, as well as possible variations in quality due to different length or catch quota management strategies; and (7) estimate the demand that would be exerted by the proposed stocked Atlantic salmon strategy upon the lake's food resource base.

2 | METHODS

2.1 | Study area

Traful is a typical oligotrophic lake of glacial origin that thermally stratifies in summer. Located within the Nahuel Huapi National Park in the Andean Range of Patagonia (Figure 1), the lake is characterised by deep, clear, well-oxygenated waters (Table 1). The terrain is mountainous with steep slopes covered with dense forests dominated by native southern beeches, *Nothofagus* spp (Blume) and Patagonian cypress, *Austrocedrus chilensis* (D. Don). Tributaries to the lake are mostly characterised by steep channels and clear, fast, cold and well-oxygenated waters. Because it is part of a national park, there are no industries or high impact activities in the area. In addition to the four salmonid species present in the lake there are four native species: small puyen, *Galaxias maculatus* (Jenyns), big puyen, *Galaxias platei* (Steindachner), creole perch, *Percichthys trucha* (Valenciennes), velvet catfish, *Olivaichthys viedmensis* (MacDonagh); of which, only the creole perch is caught by fishers.

The sport fishing season extends from 1 November to 1 May (late spring to late autumn in the Southern Hemisphere). Fishers are allowed a kill quota of one fish per fisher daily between 1 December and 31 March without size restrictions. Fishing is restricted to lures and artificial flies, whether from the shore or from boats, and downrigger trolling is common.

2.2 | Suitability of tributary streams as spawning and breeding grounds for salmonids

Five tributary streams covering all main basins and stream types draining into the lake were chosen to investigate spawning and

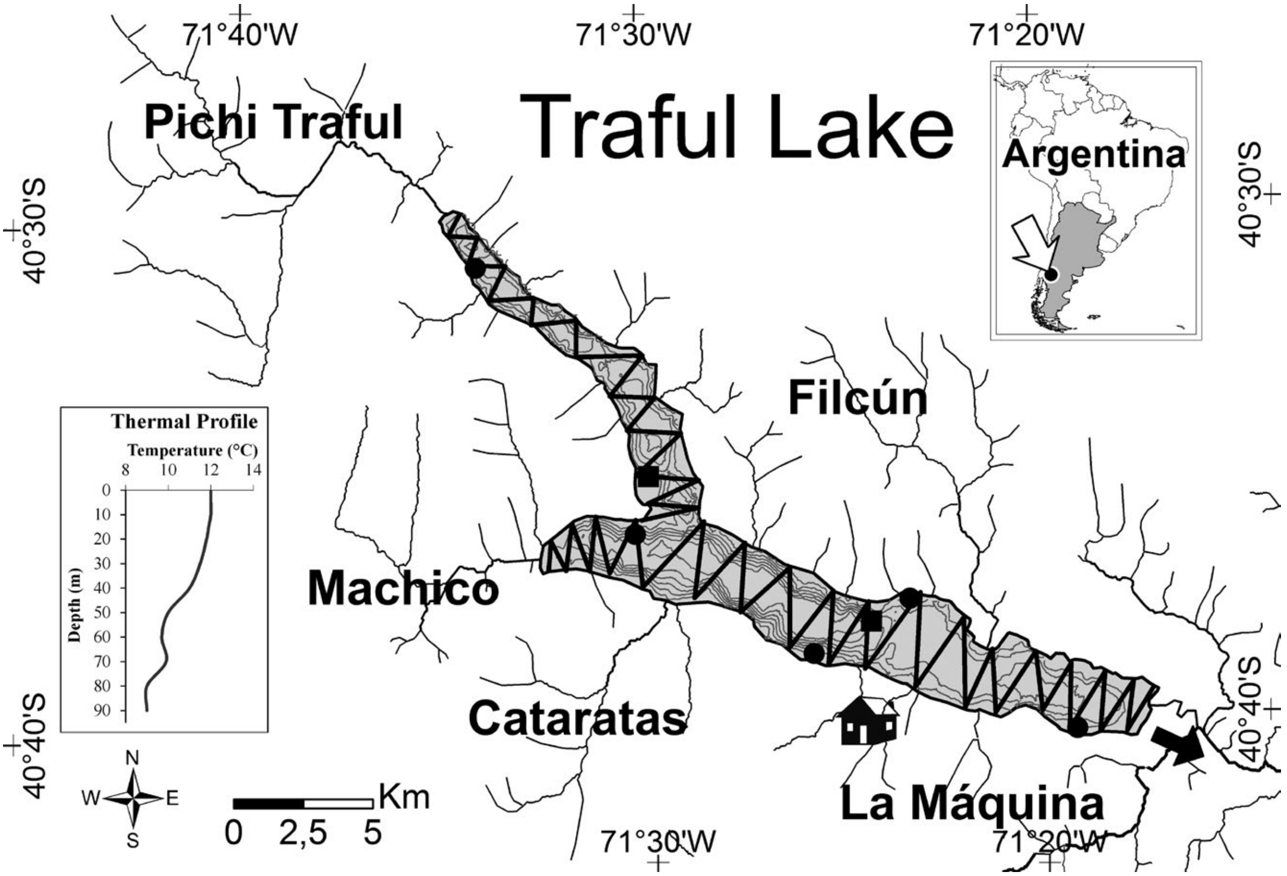

FIGURE 1 Traful Lake study area, showing hydroacoustic transects (thick black lines), littoral and benthic sampling stations (black circles), limnetic sampling stations (black squares), isobaths layers (grey lines), outlet to Traful River (black arrow), Traful village (black house), streams (thin black lines). The lake's summer thermal profile is shown in the inset

TABLE 1 Traful Lake characteristics and summer water quality parameters

Variable	Value
Surface (km^2)	71.5
Altitude (m above sea level)	720
Average depth (m)	173
Maximum depth (m)	339
Maximum length (km)	23.50
Maximum width (km)	3.52
Volume (hm^3)	10,262
Secchi disc transparency (m)	17
pH	7.9
Conductivity (µS/cm)	41.8
Dissolved oxygen (µg/L)	10.5
Soluble reactive phosphorus (µg/L)	6.51
Total nitrogen (µgl/L)	7.28

rearing suitability for Atlantic salmon: Filcún, Machico, Pichi Traful, La Máquina and Cataratas rivers (Figure 1). Temperature, pH, dissolved oxygen and conductivity as well as water velocity and channel depth, which are considered to affect productivity and survival of salmonids (Danie, Trial & Stanley, 1984; Stanley & Trial, 1995), were recorded seasonally. Sampling extended from spring 2006 to spring 2007 using a Hydrolab 6600V2 multiparameter probe, a Global Water FP111 flow meter and a gauging staff. The overall suitability of each stream for the different salmonid species was established through habitat suitability indexes (HSI), which are simple mathematical expressions that compute a unitless index of habitat quality as a function of the suitability index (SI) of one or more environmental variables relevant to the different life stages of the studied organism. The SI values are derived from bibliographic suitability curves, which show the relation between field-value variables and species quality conditions. They range from 0 (worst) to 1 (best) possible habitat conditions (Danie et al., 1984; Newcomb, Orth & Stauffer, 2007; Stanley & Trial, 1995). Presence or absence of salmonid species was seasonally verified for each stream using a model 12-B backpack electrofishing unit (Smith-Rooth Inc., Vancouver, WA, USA).

2.3 | Lake fish assemblage composition, population structures and abundances

Fish assemblage baseline conditions in terms of species composition, abundance patterns, and population structures and parameters were obtained through sampling with gillnets and hydroacoustic surveys, both following a representative, stratified, littoral-benthic and limnetic habitat sampling design. Gillnets were set once every season between winter 2006 and winter 2007. All gillnets were 70 m long and 2 m high, each consisting of seven randomly located panels of bar mesh sizes of 15, 20, 30, 40, 50, 60 and 70 mm. Specimens caught with total lengths (TL) of at least 210 mm are completely recruited to this net configuration. Gillnets were set at sunset and hauled up at dawn at 5 littoral-benthic and two limnetic sites (Figure 1). The littoral-benthic nets were set parallel to the shore following the 2, 10, 20, 30, 40 and 50 m depth contours, averaging 10 hr of soak time. The limnetic nets were set on sites over 80 m at 15 and 50 m depths. Catch data were used to compute seasonal catch-per-unit-of-effort (CPUE) standardised to 15 hr and 100 m^2 net surface area for each depth stratum and sampling site and later pooled into either limnetic or benthic catches. No attempt was made to catch fish beyond 50 m depths because previous studies in the region have shown that only adult specimens of a native fish, the big puyen, as well as galaxiid larvae (i.e. big puyen and small puyen larvae), are present at those depths (Rechencq, 2012). Small puyen is not caught by gillnets due to its small size (<100 mm total length). Each fish was identified to the species level, total length (TL) measured to the nearest millimetre and weighted to the nearest gram. Salmonid scales were removed for later age determination following Wootton (1990). To describe population size and age structures, catch data were used to draw histograms based on 20-mm TL frequency intervals superimposing age to length ranges only for salmonids.

Fish abundance was estimated in summer 2008 (stratified lake period) by hydroacoustic assessments according to an angular transects design made during daylight (Figure 1). Hydroacoustic hardware consisted of a 120-kHz split beam Biosonics DE 4000 echo sounder towed at 2 m/s. Target strengths equal or higher to -38.9 dB, which correspond to fish 260 mm in total length (Love, 1977), were include in abundance analysis (Biosonics 2004). This size limit was chosen to exclude from estimates those fish which would not be subject to fishing mortality (Vigliano et al., 2009a) according to creel census surveys. This target size threshold also excluded the small and big puyens and juvenile fish of all species. The velvet catfish, a bottom-dweller, was also excluded from the estimate because detection was unlikely in the fixed blanking zone 0.5 m off the bottom.

Hydroacoustic estimates of depth-specific fish densities were combined with depth-specific species composition from both benthic and limnetic gillnets to calculate the abundance of each species by habitat. Fish densities were estimated as number of fish m^{-3} only for gillnet operating depths, for cells 10 m in depth and 100 m in length. Total population numbers of fish in 10-m depth strata were computed separately by multiplying the average target density for all insonified cells in the stratum × total volume. Estimated total abundances were partitioned among species by habitat and depth strata according to the CPUE percentage of each species in the gillnet catches.

The Fishery Analyses and Simulation Tools (FAST) software was used (Slipke & Maceina, 2001) to determine population parameters. Catch numbers, age, length and weight of each species were used as inputs for FAST software to estimate growth (von Bertalanffy parameters, length/weight), mortality (Z, F, Cm, Cf) and recruitment to the population through reproduction. Natural mortality was estimated using Pauly's model subroutine and fishing mortality from the relationship between numbers harvested by fishers and population size following Miranda and Bettoli (2007).

2.4 | Trophic diversity and possible competition due to diet overlap

In order to establish possible relationships between species and trophic diversity, stomachs of all fish species were removed for the examination of food contents and analysed for prey composition under a dissecting microscope (Wallace, 1981). Prey was grouped into 13 categories: (1) large plant material, (2) Galaxiids, *Galaxias* spp., (3) salmonids, (4) velvet catfish, (5) salmonid eggs, (6) larvae, nymphs and Insect pupae, (7) adult terrestrial and aquatic Insects; (8) insect exuviae and remains; (9) freshwater crabs, *Aegla* sp., (10) crayfishes, *Samastacus* sp., (11) amphipods, Amphipoda; (12) snails, *Chilina* sp., (13) other molluscs.

Diet was quantified as weight in grams of each prey type (i)/total number of fish of species (j) (Chipps & Garvey, 2007). The relative importance index (RII)] expressed as %RII was calculated for each prey category by the equation $RII = FO\ (V + N)$ (Pinkas, Oliphant & Iverson, 1971), where FO is the frequency of occurrence of each diet item, N the number of each diet item and V the volume of each diet item. Shöener's index, used to analyse trophic overlaps between species (Schöener, 1970), was estimated as $1 - (0.5 \cdot \Sigma\ (P_{ij} - P_{in}))$, where P_{ij} and P_{in} are the proportions of RII of each prey item (i) of species (j to n). This index ranges from 0 (no overlap) to 1 (total overlap); an index value ≥0.60 is considered a significant overlap (Wallace, 1981).

2.5 | Bioenergetic model simulations of consumptions

The Wisconsin Bioenergetics Model of Hanson, Johnson, Schindler and Kitchell (1997) was used to estimate the potential demand in terms of annual food resources for all salmonid populations and food resources that would be necessary to sustain stocked numbers of Atlantic salmon. The inputs of the model were thermal experience and lifetime prey consumption for each species. Gillnet catches were the primary source for the analysis of diet composition, annual growth and population parameters. Thermal experience was determined by comparing catch per depth stratum to thermal profiles registered with an YSI 6200V2 probe (Figure 1). Daily, seasonal and annual consumption of the different prey items for individual fish of each salmonid species were estimated and later expanded to the hydroacoustically estimated abundances of each species age group.

Seasonal diet composition for each species was expressed as proportional wet weight contributions to the total diet. Prey items were grouped into 10 categories excluding indigestible materials (i.e. plants, exuviae and insect remains), grouping salmonids eggs into salmonids as well as all molluscs together and separating galaxiids into larvae and adults due to their differential energy densities. The proportional weight contribution of each category to the diet of each predator was computed for each stomach individually and then averaged across all non-empty stomachs within the same season and predator size-class (Chipps & Garvey, 2007). Energy contents of different prey were taken from the literature (Ciancio & Pascual, 2006; Ciancio, Pascual & Beauchamp, 2007) and assumed to be constant throughout the year (Table 2). Energy densities of predators were estimated using the specific weight-dependent functions from each species model. Energy balance equations and species-specific parameters from literature were used for the simulations of rainbow trout (Rand, Stewart, Seelbach, Jones & Wedge, 1993), brown trout (Dieterman, Thorn & Anderson, 2004), brook trout (Hartman & Cox, 2008) and Atlantic salmon (Danie et al., 1984). Consumption was not simulated for native species due to lack of specific models.

The average proportion of the maximum consumption rates were fitted to the annual growth increments from the von Bertalanffy curves derived by FAST using the *p*-fit routine in the Wisconsin Bioenergetics Model. Model runs were 365 days long, with different initial dates following the timing of the growth season of each species as proposed by Juncos, Beauchamp and Vigliano (2013). Spawning losses of 8% body mass were applied to ages 3 and older on simulation day 335 (Juncos et al., 2013). Model simulations estimated the daily consumption rates of each prey category for individuals of each age class and species. These were summed into annual totals to determine the biomass contribution of each prey to the annual and lifetime energy budgets of the different salmonids. To expand individual consumption rates to population-level consumption estimates, age-specific abundance of each predator was fitted iteratively to an initial abundance for the first age recruited to the lake [assuming a constant survival (S) for all ages], such that the resulting total abundance of the considered ages summed up to the hydroacoustic abundance estimate for each species in the lake.

2.6 | Sport fishery structure, quality and scenario simulations

The Fishery Analyses and Simulation Tools (FAST) software (Slipke & Maceina, 2001) was used to determine sport fishery structure and quality and to simulate the possible outcomes of alternative management scenarios. Incremental population stock density and average relative weight indices were used to describe population size structures. Incremental indexes use pre-determined criteria to establish the percentage of specimens among the following fish size range categories: stock to quality, quality to preferred, preferred to memorable and memorable to trophy (Anderson & Neumann, 1996; Neumann & Allen, 2007). Due to the fact that fisher's criteria for these categories by species differed from those included in the software, size limit criteria derived from a roving creel survey held during the 2005–2006 fishing season were used (Vigliano et al., 2009a). Relative weight indices for each species and size category, as defined by fisher's criteria, were calculated using the respective average weights and length-specific standard weights predicted from the weight/length relationships. Fish with relative weight index values in the range 95-105 were considered in good condition (Pope & Kruse, 2007).

TABLE 2 Energy density values (J/g of wet weight) of prey consumed by Salmonids in Patagonian lakes (Ciancio & Pascual, 2006; Ciancio et al., 2007)

Prey type	Energy density (J/g wet mass)
Galaxiid larvae	2.879
Small puyen adults	3.540
Other fishes	6.040
Insect larvae and pupae	2.062
Adult insects	5.296
Freshwaters crabs *Aegla* spp.	3.731
Crayfishes *Samastacus* spp.	3.974
Amphipods	4.429
Mollusks	1.705

Both the Yield per Recruit (YR) and the Dynamic Pool (DP) models of FAST were used to study possible simulated outcomes of implementing size limit regulations as well as shifts in fish community structure as proposed by CEAN (Centro de Ecología Aplicada del Neuquén) (2002). The YR model was used to simulate changes in yield, mean number harvested, mean TL and mean weight of fish harvested for rainbow, brown and brook trout when increasing instantaneous fishing mortalities while holding a constant natural mortality, under varying minimum size limit regulation scenarios. These regulations mandate retention of all trout specimens equal to or larger than the minimum size limit, while maintaining a mandatory catch and release policy for Atlantic salmon. Three different scenarios were simulated for the other salmonids. The first scenario corresponds to the present situation, with no size limit regulation and where 120 mm is the minimum average size that is caught and usually released by fishers according to creel census data (Vigliano et al., 2009a). The second and third scenarios corresponded to the sequentially smaller sizes of rainbow, brown and brook trout that fishers consider to be of stock or quality categories as revealed by on site creel census interviews (Vigliano et al., 2009a). Input parameters for the models were those estimated from the catch data as explained above.

The DP model was used to simulate possible outcomes of the proposed stocking strategy of Atlantic salmon (CEAN 2002) in terms of stocked numbers of: total Atlantic salmon, age 1, stock, quality, preferred, memorable and trophy size fish. Assuming that the number of 0 + specimens to be stocked annually on the lake would remain constant, as proposed by CEAN (i.e. 10,000/years), the simulations were run for the minimum number of years necessary to attain a stable pattern after stocking is stopped on year 12. The contribution of reproduction of stocked specimens throughout the years of the simulations was estimated through FAST computation of the static spawning potential ratio. Number of eggs were estimated for 50 % of all females reaching age 3 and 100 % of those reaching age 4 and over, through a length fecundity relationship (Slipke & Maceina, 2001). In these simulations, the no kill regulation for this species implies an instantaneous fishing mortality equal to zero and a constant natural mortality estimated from wild specimens caught on the lake.

Finally, the amount of food resources that would be required to maintain a steady population level of stocked Atlantic salmon was analysed using the estimated consumptions from the Bioenergetic model and the population numbers from the Dynamic Population simulation.

3 | RESULTS

3.1 | Suitability of tributary streams as spawning and breeding grounds for salmonids

Sampling to evaluate stream suitability as spawning and breeding grounds revealed year around presence of all salmonid species except for Atlantic salmon. This was consistent with the HSI values found for the different salmonids, which were adequate for rainbow, brown and brook trout, but low for Atlantic salmon (Table 3). Two variables, water velocity and temperature during the spawning and fry growth periods, were responsible for low HSI values for the latter species (Table 3). Water velocities were between 90 and 130 cm/s, which imply SI's between 0 and 0.2. Also, maximum SI temperature values during the spawning and early growth critical periods were always either at 0 or below 0.2 for all streams. Thus, accordingly the overall HSI water quality values for Atlantic salmon for any of the streams were between 0 and 0.3. By contrast, rainbow, brown and brook trout showed HIS values of 0.3 and 0.9. Thus, SI and HSI values were consistent with the lack of Atlantic salmon catches for the streams in all seasons.

3.2 | Lake fish assemblage composition, population structures and abundances

The baseline fish assemblage of the lake was numerically dominated by small puyen, followed in decreasing abundance by rainbow, brook and brown trout, Atlantic salmon, big puyen, velvet catfish, and creole perch. The dominance of small puyen, which is not caught by gillnets, was determined by the observation of large shoals of this species and its estimated consumption numbers by salmonids through bioenergetic models (see below). Gillnet catches (Figure 2) showed that numbers of Atlantic salmon caught were the lowest among salmonids, except in summer when its abundance was more than twice and similar to those of brown and brook trout. Except for creole perch, which was always scarce, Atlantic salmon catches were also lower than for native species.

Baseline information regarding length and age structures of all species (Figure 3), as well as salmonid population parameters (Table 4) and salmonid hydroacoustic and gillnet-derived distributions by depth (Table 5), was like those found for other lakes in the region. Distribution along the water column showed that all salmonid species tend to have higher abundances in the upper 30 m.

3.3 | Trophic diversity and possible competition due to diet overlap

A total of 515 stomachs (rainbow trout—211; brook trout—126; brown trout—92; Atlantic salmon—30; velvet catfish—28; big puyen—21; creole perch—7) were analysed to establish trophic diversity and possible competition due to diet overlap; of these, 72 were empty. The %RII index values showed that galaxiids (38%), amphipods (26%) and crayfish (24%) constituted the most important prey. Salmonids are the most trophically diverse, while native fish are the least diverse. Rainbow trout is the most generalist feeder;

TABLE 3 Suitability index (SI) and habitat suitability indexes (HIS) values for all Salmonid species in the five studied streams of the Traful Lake in relation to spawning and fry stages.

		Stream				
Species	Variables	Catarata	La Máquina	Filcún	Pichi Traful	Machico
RT	SI–WT	1.00	1.00	1.00	0.90	0.90
	SI–WV	0.00	0.90	0.90	0.90	0.90
	HSI	0.50	0.90	0.90	0.90	0.90
	Presence	*	*	*	*	*
BwT	SI–WT	1.00	1.00	1.00	1.00	0.90
	SI–WV	0.00	0.00	0.90	0.50	0.90
	HSI	0.30	0.50	0.90	0.80	0.80
	Presence	*	*	*	*	*
BkT	SI–WT	1.00	1.00	1.00	1.00	1.00
	SI–WV	0.00	0.50	0.30	0.30	0.50
	HSI	0.30	0.75	0.50	0.50	0.75
	Presence	*	*	*	*	*
AS	SI–WT	0.20	0.20	0.10	0.00	0.00
	SI–WV	0.00	0.00	0.10	0.10	0.20
	HSI	0.00	0.29	0.23	0.13	0.11
	Presence	°	°	°	°	°

Species: Rainbow trout (RT), Brown trout (BwT), Brook trout (BkT), Atlantic salmon (AS). Variables: water temperature (SI-WT), water velocity cm/seg (SI-WV), Species Presence: present (*) or absent (°) in the stream

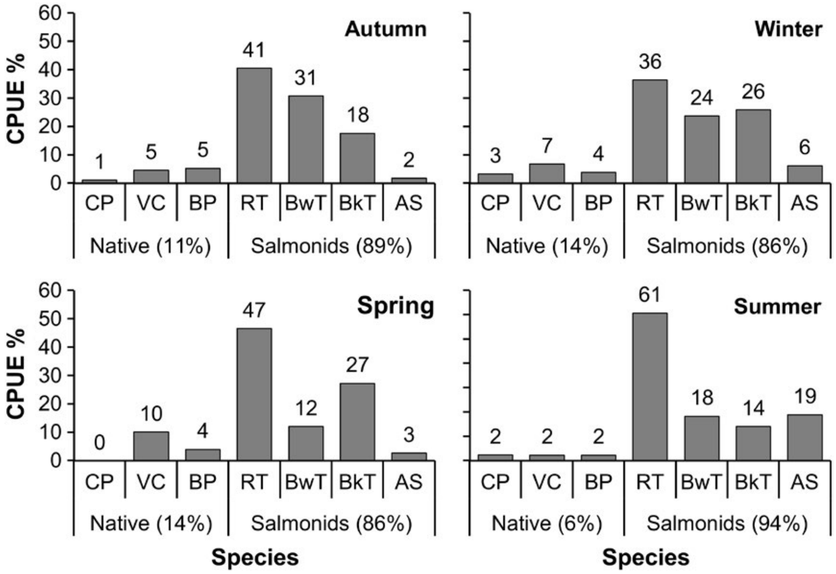

FIGURE 2 Seasonal percentual catch-per-unit-of-effort (CPUE%). Native fish: Creole perch (CP), Velvet catfish (VC), Big puyen (BP), Salmonids: Rainbow trout (RT), Brown trout (BwT), Brook trout (BkT), Atlantic salmon (AS)

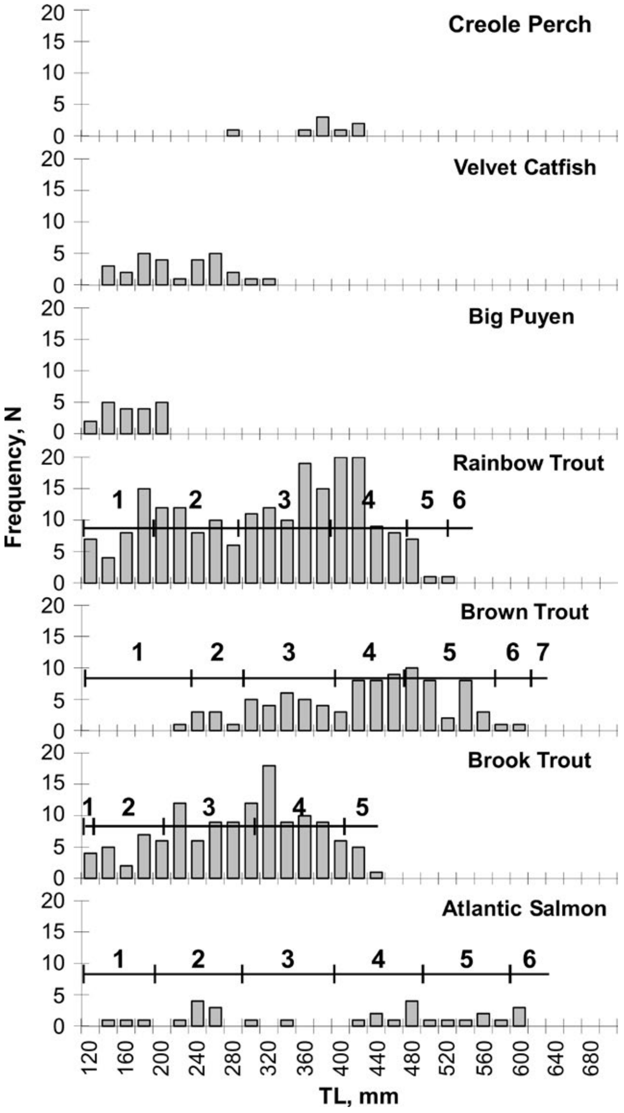

FIGURE 3 Size structure of gillnet caught fish species and age structures of Salmonids. Total length in mm (TL), frequency (N), age groups (black lines), no age data are available for native species

in contrast, Atlantic salmon feeds almost entirely on galaxiids (Figure 4).

Possible competition due to dietary overlap, analysed through Shöener's index (Table 6), showed that the native velvet catfish and big puyen have the highest significant overlap because of the common consumption of crayfishes and amphipods. Creole perch overlaps with brook trout for various diet items. Piscivory by both Atlantic salmon and creole perch upon galaxiids showed a high overlap between them, but the numbers of creole perch caught were too low to yield a statistically significant result. The overlap at the 0.6 limit between rainbow trout and brook trout is due to the common consumption of crayfishes and galaxiids, although crayfish were more important for rainbow trout than for brook trout. The overlap between the big puyen and rainbow trout is due to common consumption of crayfishes and galaxiids. It is noteworthy that rainbow trout and Atlantic salmon do not show a significant overlap.

3.4 | Bioenergetic model simulations of consumptions

The results of bioenergetic simulations of current salmonid populations by age group (Figure 5) showed that impacts upon different prey items are conditioned by varying population numbers and age, resulting in species-specific differential impacts upon different prey. Thus, rainbow trout population impacts galaxiids as well as molluscs at all ages but increases crayfish consumption at higher ages. Brown trout impact mostly on freshwater crabs at age 4 and on salmonids at age 5. Galaxiids are consumed to a lesser extent throughout all ages. Brook trout impact mainly upon galaxiids at ages 2 and 3, shifting to higher consumption of insect larvae and pupae, freshwater crabs and crayfishes from age 3 onwards. Atlantic salmon was predominantly piscivorous, preying upon galaxiids during their entire lifespan, incorporating adult insects, amphipods and crayfish from age 3 onwards. Simulations indicated that current salmonid populations consume over 489,000 kg of galaxiids per year, most of which (319,000 kg) correspond to galaxiid larvae.

TABLE 4 Growth curves and population parameters estimated for Salmonid species present in Traful lake

	von Bertalanffy's growth curve parameters			
	Species			
	RT	BwT	BkT	AS
L_{inf}	841.27	900.12	553.99	792.13
K	0.174	0.170	0.290	0.290
T_0	−0.173	−0.120	−0.280	0.290
W_{inf} g	6385.86	8437.93	2115.51	5105.63
R^2	0.99	0.99	0.99	0.96
prob > F	0.0001	0.0001	0.0010	0.0001
	Population models input parameters			
	Species			
	RT	**BwT**	**BkT**	**AS**
A	0.74	0.56	0.42	0.43
Z	1.36	0.82	0.54	0.55
μ	0.001	0.001	0.001	0.008
F	0.003	0.002	0.001	0.011
M	1.36	0.81	0.54	0.54
cm	0.74	0.56	0.42	0.42
cf	0.003	0.002	0.002	0.011
S	0.26	0.44	0.58	0.57
Max age yr.	7.1	9.0	9.8	6.8
R^2	0.98	0.77	0.99	0.89
prob > F	0.09	0.31	0.05	0.01

Von Bertalanffy parameters: TL in mm of infinitely old fish (L_{inf}), growth coefficient (K), time in years when TL is theoretically equal to zero (T_0), weight in g of infinitely old fish (W_{inf} g), model fit (R^2, prob > F). Population models input parameters: annual mortality (A), instantaneous total mortality rate (Z), exploitation rate (μ), instantaneous fishing mortality rate ($F = \mu Z/A$), instantaneous natural mortality rate ($M = Z - F$), conditional mortality ($cm = 1 - e^M$), conditional fishing mortality ($cf = 1 - e^F$), survival (S) and maximum theoretical age in years (Max age yr). Species: Rainbow trout (RT), Brown trout (BwT), Brook trout (BkT), Atlantic salmon (AS).

TABLE 5 Estimated densities from hydroacoustic data: average fish per/m^3 [AFM-3], standard deviation (Sd), 95% minimum confidence limit (Min Lim), 95% maximum confidence limit (Max Lim), total number of

	Estimated overall fish density			
	AFM-3	SD	Min Lim	Max Lim
	0.00018	0.00372	0.00012	0.00029
	Estimated abundance by depth Strata			
	Species			
Depth (m)	**RT**	**BwT**	**BkT**	**AS**
0–10	50,969.95	10,978.14	21,956.29	10,193.99
10–20	65,960.56	27,160.23	34,920.30	19,400.17
20–30	109,178.75	31,193.93	54,589.38	7,798.48
30–40	39,218.66	22.410,66	25,211.99	- - -
40–50	23,402.51	- - -	18,722.01	9,361.00
Total	288,730.43	91,742.97	155,399.96	46,753.64

Salmonid fish (N) down to gillnet operating depths. Species: Rainbow trout (RT), Brown trout (BwT), Brook trout (BkT), Atlantic salmon (AS). "- - -" indicates not estimated because of lack of catches of the species in the depth strata

3.5 | Sport fishery structure, quality and scenario simulations

Analysis of size limits, as defined by fishers for the stock, quality, preferred, memorable and trophy to fish length categories, showed that they were the same for all salmonid species except for brook trout, for which limit values were lower (Table 7). The incremental stock density indices for salmonid sport fishery structure and quality (Table 7) are characterised by rainbow trout having many fish on the ranges: stock to quality (PSS_{SQ}) and quality to preferred (PSS_{QP}). Most brown trout are in the range of preferred to memorable (PSS_{PM}), with some specimens reaching trophy class size. Brook trout specimens ranged from stock to quality (PSS_{SQ}) size. The Atlantic salmon caught were mostly preferred to trophy (PSS_{PT}) size. Analysis of the relative weight index values (Table 7) showed that all salmonid species in the lake index values were close to 100, indicating that they were well fed and in good condition.

The YR model simulations gave similar results for rainbow, brown and brook trout (Figures 6–8) as to possible outcomes of trying to reduce population numbers through an increase in F or of implementing size catch limits of stock and quality size for the three possible scenarios. Rainbow trout simulations using the present conditional natural mortality rates for the first scenario (i.e. 120 mm TL) indicate that increases in *F* would result in a higher number of harvested fish. Yield would decrease after *F* increases by at least one order of magnitude, due to a decrease in size and weight of the fish caught (Figure 6). Simulation of the other two scenarios for this species (i.e. 260 mm TL; 400 mm TL) showed that imposing higher minimum size limits with increasing *F* would reduce the number harvested, but yield would increase due to the greater size and weight of specimens caught.

For brown trout, the three scenarios showed similar trends to those of rainbow trout, with the exception that decreases in yield occur for the first scenario at the 0.7 *F* level (Figure 7).

For brook trout, the three scenarios (Figure 8) showed that reduction in yield for the 120-TL minimum length limit would occur at a *F* level of 0.6 and for the 220-TL limit at an *F* of 1.2. The 320 length limit of the third scenario did not show a decrease on yield on the range of examined *F* values.

The DP simulation of the proposed Atlantic salmon stocking strategy (Figure 9) showed that overall numbers of stocked Atlantic salmon would initially increase and stabilise around year 12. Interruption of stocking would bring about a rapid decrease in recruits and a consequent decrease in numbers. Numbers of quality, preferred and memorable size fish would be low throughout the experience.

The amount of food consumed by an Atlantic salmon of each age group according to bioenergetic modelling and the numbers of

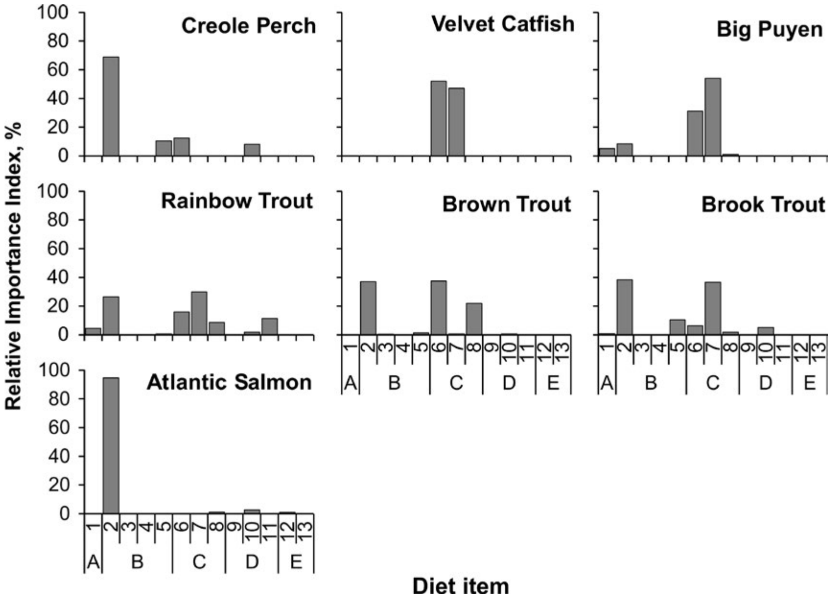

FIGURE 4 Trophic diversity and percent relative importance index (RII) in grams per number per fish species. Diet item categories: A. Plants: (1) Plants; B. Fish: (2) Galaxiids, (3) Salmonids, (4) Velvet catfish, (5) Salmonid eggs; C. Insect: (6) Larvae, nymphs and pupae, (7) Adult terrestrial and aquatic, (8) exuviae and remains; D. Crustacean: (9. Freshwater Crabs *Aegla* spp., (10) Crayfishes *Samastacus* spp., (11) Amphipods *hyallella* spp.; E. Mollusks: (12) Snails *Chilina* sp., (13) Other

TABLE 6 Schöener dietary overlap indexes.

Species	VC	BP	RT	BwT	BkT	AS
CP vs	0.13	0.21	0.42	0.52	0.60*	0.72*
VC vs		0.79*	0.47	0.39	0.44	0.01
BP vs			0.60*	0.42	0.54	0.10
RT vs				0.53	0.68*	0.30
BwT vs					0.48	0.39
BkT vs						0.43

Fish species: Creole perch (CP), Velvet catfish (VC), Big puyen (BP), Rainbow trout (RT), Brown trout (RwT), Brook trout (BkT), Atlantic salmon (AS). Values with * indicate significant overlap (≥ 0.60)

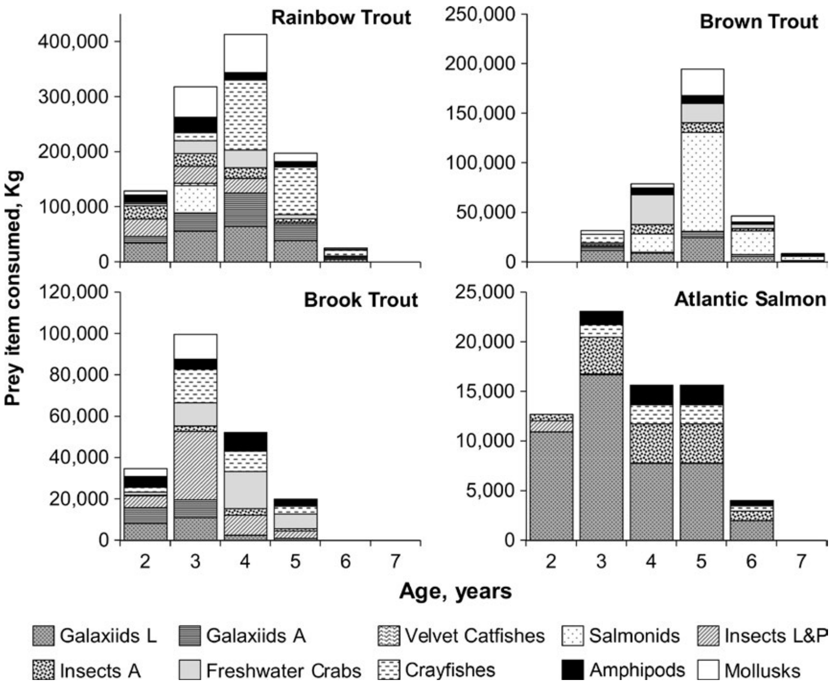

FIGURE 5 Traful Lake Salmonid populations bioenergetic simulation of consumed prey items by age group in: Larvae (L), Pupae (P), Adult (A). The *y*-axis on the graph by species is on different scales

stocked specimens of each cohort on year 12 according to the DP model were used to estimate the overall amount of food that they would consume. The current Atlantic salmon population consumes 3.6% of the overall salmonid consumption, but a stocked (larger) stable Atlantic salmon population would theoretically consume 1.17% of the overall total.

TABLE 7 Sport fishery quality and structure values: Size categories limits (Total length in mm) defined by fishers through Creel Census, incremental population stock density (%) and average relative weight (unitless) indexes for Salmonid species in Traful Lake.

	Size categories limits				
Species	**Stock**	**Quality**	**Preferred**	**Memorable**	**Trophy**
RT	260	400	500	600	800
BwT	260	400	500	600	800
BkT	220	320	400	500	600
AS	260	400	500	600	800
	Incremental population stock density indexes				
	PSS_{SQ}	PSS_{QP}	PSS_{PM}	PSS_{MT}	
RT	39.95	48.39	12.26	0.00	
BwT	27.17	23.91	38.04	10.87	
BkT	51.72	24.14	24.14	0.00	
AS	31.82	4.55	40.91	22.73	
	Average relative weights				
	Stock	Quality	Preferred	Memorable	Trophy
RT	103.48	100.32	98.14	0.00	0.00
BwT	97.80	110.08	98.69	95.84	0.00
BkT	104.56	102.33	99.31	0.00	0.00
AS	107.69	117.75	99.38	94.01	0.00

Species: Rainbow trout (RT), Brown trout (BwT), Brook trout (BkT), Atlantic salmon (AS). Incremental population stock density indexes for ranges defined by Size categories limits: stock to quality (PSS_{SQ}), quality to preferred (PSS_{QP}), preferred to memorable (PSS_{PM}), memorable to trophy (PSS_{MT}) ranges

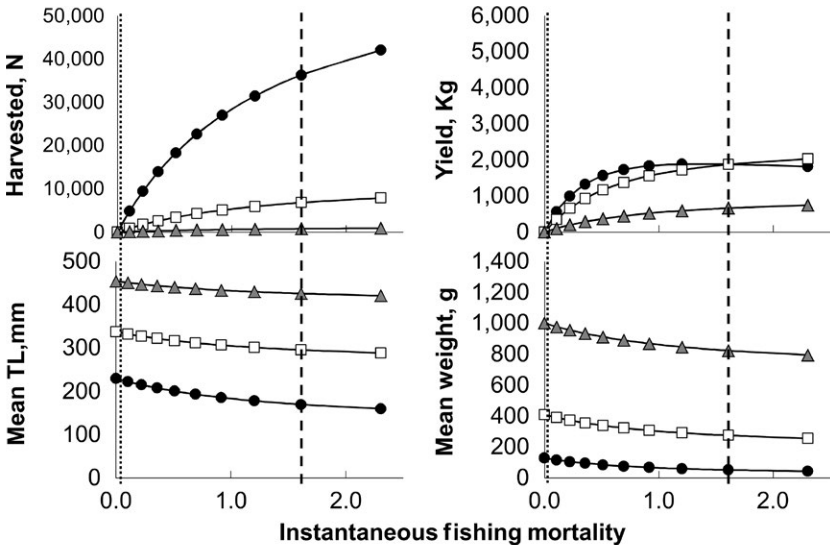

FIGURE 6 Rainbow trout simulation of variations in: Numbers Harvested, Yield, Mean Total Length (mm) and Mean Weight of fish caught as a function of instantaneous fishing mortality (F) for varying possible minimum length limit regulations. Scenarios: 1–120 mm TL (black circle), 2–260 mm TL (white square), 3–400 mm TL (grey triangle). Actual level of F (dotted line), Simulated level of F necessary to achieve a reduction in Yield under the first scenario (dash line)

4 | DISCUSSION

The suitability indexes for water temperature and water velocity indicated that streams were inadequate for the spawning, fry and juvenile stages of Atlantic salmon. Thus, even though the streams may have some adequate sites for spawning and rearing of Atlantic salmon, the amplitude of the oscillations of critical environmental variables would diminish the importance of the streams for this species. This being the case it may be concluded that Traful Lake lacks suitable tributaries for spawning and rearing of juveniles of Atlantic salmon.

Fish assemblage composition in Lake Traful is atypical for Argentinian Northern Patagonia. Most lakes of the region normally have fish assemblages lacking Atlantic salmon and structured around dominant small puyen populations followed in terms of abundance by creole perch, rainbow, brook and brown trout, big puyen and velvet catfish, with brown trout being the top predator (Pascual et al., 2002). By contrast, in Traful Lake creole perch is scarce and Atlantic salmon is present. Baseline data reported in this work, such as population parameters, size and age structure, growth and hydroacoustically derived densities by depth, agree with those generally found in

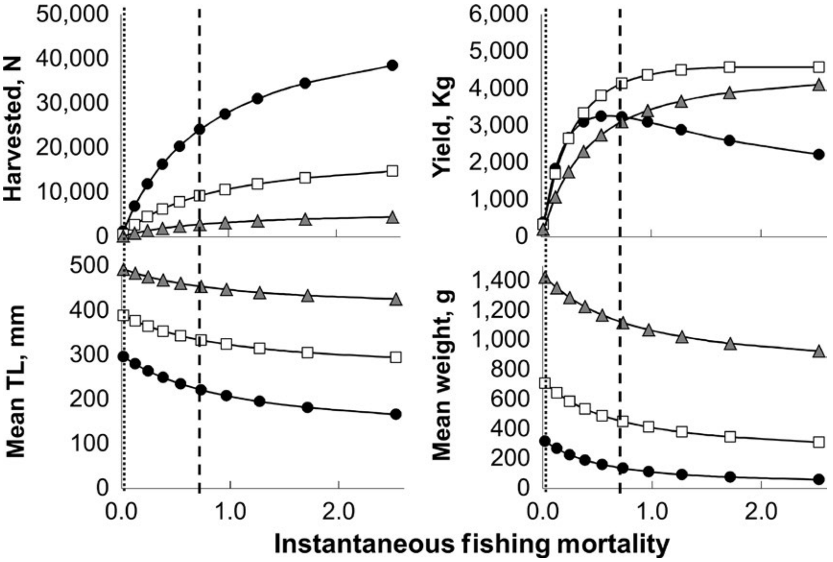

FIGURE 7 Brown trout simulation of variations in: Numbers Harvested, Yield, Mean Total Length (mm) and Mean Weight of fish caught as a function of instantaneous fishing mortality (F) for varying possible minimum length limit regulations. Scenarios: 1–120 mm TL (black circle), 2–260 mm TL (white square), 3–400 mm TL (grey triangle). Actual level of F (dotted line), Simulated level of F necessary to achieve a reduction in Yield under the first scenario (dash line)

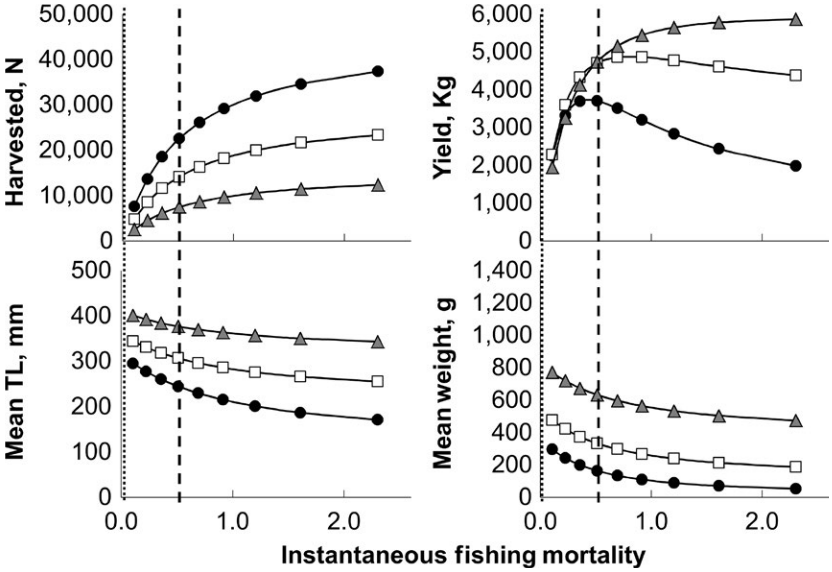

FIGURE 8 Brook trout simulation of variations in: Numbers Harvested, Yield, Mean Total Length (mm) and Mean Weight (g) of fish caught as a function of instantaneous fishing mortality (F) for varying possible minimum length limit regulations. Scenarios: 1–120 mm TL (black circle), 2–220 mm TL (white square), 3–320 mm TL (grey triangle). F actual level (dotted line), Simulated level of F necessary to achieve a reduction in Yield under the first scenario (dash line)

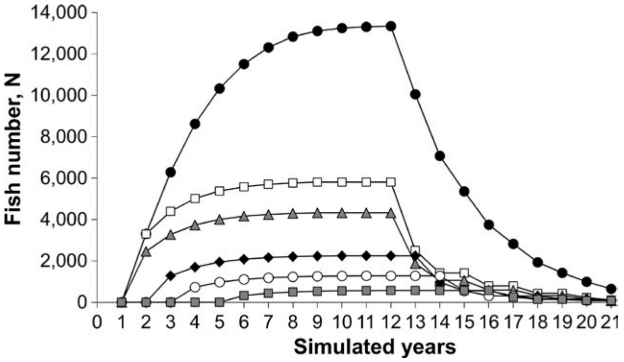

FIGURE 9 Dynamic pool model simulation of variation in numbers (*N*) of stocked Atlantic salmon: total (black circle), age 1 (white square), stock size (grey triangle), quality size (black rhombus), preferred size (white circle) and memorable size (grey square)

other lakes in the region (Juncos, Milano, Macchi, Alonso & Vigliano, 2011; Juncos, Milano, Macchi & Vigliano, 2015; Juncos et al., 2013; Rechencq, Sosnovsky, Macchi, Alvear & Vigliano, 2011; Rechencq, Vigliano, Macchi & Lippolt, 2014; Vigliano et al., 2009b). Thus, none of these variables explain why this lake is different in its assemblage structure, a question that warrants further studies.

General trophic diversity in Traful Lake is similar to that found in other lakes in the region. Although fishers and the CEAN (Centro de Ecología Aplicada del Neuquén) (2002) state that high numbers of rainbow trout are outcompeting Atlantic salmon for food, trophic diversity and Shöener's dietary overlap index values reported here do not support this claim. Atlantic salmon only significantly overlap diets, and thus potentially competes, with creole perch. Competition for food resources with creole perch, which is highly abundant in most lakes in the region, could explain why Atlantic salmon is not found in them. However, given the scarcity of creole perch in Traful Lake, competition cannot explain the overall low numbers of Atlantic salmon in this water body. Unfortunately, there are no records about fish composition and dominance patterns before the introduction of Atlantic salmon in Traful Lake, so it is not possible at present to determine whether scarcity of creole perch was a cause or a consequence of this introduction.

Bioenergetic modelling showed differential species-specific population pressures depending on population numbers and structures. Galaxiid larvae are consumed by all current salmonid populations, but are the main diet item only for Atlantic salmon. The overall numbers of larvae consumed by salmonids would indicate that this group, which is mainly comprised by small puyen, is the most abundant item in the lake.

The sport fishery structure and quality are characterised by rainbow trout and brown trout having well-balanced populations with index values indicating that their numbers are intermediate between the extremes of a large number of small fish and a small number of large fish. Brook trout and Atlantic salmon populations do not appear to be balanced. Brook trout has a large number of stock and quality fish, whereas Atlantic salmon has a more disjointed distribution biased towards both ends of the size spectrum. Relative weight indices indicate that all species are well fed; therefore, food availability would not be a limiting factor at present.

Analysing the results of the YR simulation of proposed management scenarios of increasing the catch kill quota indicates that *F* and, therefore, effort would have to be increased to unattainable levels to have a depleting effect upon rainbow trout. Furthermore, the YR models also predict that both brown trout and brook trout could experience depleting effects at lower *F* values than rainbow trout. Mandatory release of these two species would not necessarily prevent this effect because an unknown proportion of all released fish die. Simulations also suggest that an increase in length limits for all species could be a better strategy to increase fishing quality because, even if it would lead to a lower number of catches per fisher, it would also increase the average size of fish caught despite the simulated excessive increase in *F*.

The DP model forecasts that stocking Atlantic salmon would not be feasible because most fish would be of sizes of low value to fishers and numbers would decline rapidly as soon as stocking ceased. Furthermore, lack of adequate tributaries for spawning and rearing of Atlantic salmon, as indicated by the HSI values, implies that there is no guarantee that stocked specimens would successfully reproduce allowing for a larger self-supporting population. Simulation results are consistent with no apparent change in the Atlantic salmon population observed by fishers (Vigliano et al., 2009a), despite the continuing, off-the-record stocking.

Simulation of consumptions through bioenergetic models showed that the food resource demand required by stocked Atlantic salmon would imply a redistribution of available resources among species. The proportion of resources that should be redistributed when the stocked specimens reach stable numbers would be negligible in relation to total consumption by all salmonids in the lake. Also redistribution of food resources may or may not occur at the levels necessary to sustain re-stocked specimens.

4.1 | Case study conclusions

Fishers and local developmental organisations have argued that an increase in Atlantic salmon numbers in Traful Lake would result in the establishment of a unique and distinctive sport fishery in Argentinian Patagonia. Based on the evidence and simulations reported, trying to change Traful Lake's present fish assemblage structure is not advisable. Although adult Atlantic salmon can be caught on the lake, their numbers have always been low in relation to the other salmonids. The findings indicate that the current status Atlantic salmon in the lake's fish assemblage is probably due to the interaction of several limiting factors.

An increase in numbers of Atlantic salmon would require a redistribution of food resources. A reduction in numbers of the other salmonid species through increased selective fishing mortality would undoubtedly liberate food resources. However, because YR models seem to indicate that there is no feasible way to increase mortality of the other salmonids to the necessary levels through a proposed fisher's extraction, there seems to be no point in trying to undertake such a strategy.

Policymakers must consider that stocking Atlantic salmon in an attempt to increase its numbers is actually an attempt to induce a shift away from a naturally acquired dynamic equilibrium that has existed for more than a hundred years. Considering that the processes shaping and determining the actual equilibrium are not fully understood, such an attempt is not likely to result in a new equilibrium with the desired characteristics. What is more, it may bring about unforeseeable effects upon the lake's fish assemblage structure. Given the results and the uncertainties related to the possible outcomes, this study concluded that it is not advisable to try to generate a unique and distinctive lake sport fishery by stocking Atlantic salmon in an already renowned fishery in Northern Patagonia.

4.2 | Implications for policy and management

As pointed out earlier one of the major problems for fisheries management in Argentina is that policies and strategies are usually oriented to target species, without considering the context of biophysical and sociological constraints imposed by the system in question. Thus, the usual approach is to address a perceived problem in a restricted way, considering only aspects of a complex problem. Management requires understanding of the dynamic interactions between the human factor and the abiotic and biotic environments (Nielsen, 1999). This study shows that short-term studies may be designed and implemented taking into account more than just the target species and/or the perceived problem. Abiotic, biotic and human factors can be taken into consideration to apply various approaches and modelling strategies, providing for a more comprehensive framework on which to base decisions.

In Argentinian Patagonia, the lack of context-oriented strategic planning and policies is a major issue (Macchi & Vigliano, 2014; Macchi et al., 2008; Pascual et al., 2007); therefore, there is a crucial need to have qualified people in decision-making positions. While in many other countries, historical development of fisheries management placed people with scientific management backgrounds in key positions (Jackson, Moffitt & Whelan, 2010); in Argentina, this has never been common. As a result, advice given by researchers is often misunderstood and/or ignored by decision-makers. Therefore, if sound management of fish resource is to be accomplished, two progressive steps should be undertaken. The first and perhaps most important is to implement policies based on qualified people (i.e. with managerial and scientific background training) in decision-making positions especially at the local, regional and provincial levels. The second is to have decision-makers made aware that evaluation and management must rely on solid databases, to allow for accurate descriptions of the problem at hand and the use of predictive models to simulate varying scenarios, as exemplified in this case study. The type of approach applied in this study should become the norm and not the exception in management issues of freshwater ecosystems in Argentina and elsewhere, whether related to fisheries, management of biological invasions or conservation of biodiversity.

ACKNOWLEDGMENTS

We wish to thank the "Autoridad Interjurisdiccional de Cuencas de los Ríos Limay, Neuquén y Negro" and Universidad Nacional del Comahue CRUB, UNCO B025 for funding and logistical support on the field; the people of Villa Traful for their support during field work. We want to thank "Pepe" and "Mauricio" our drivers for the support and help further than duty demands. We also want to thank the reviewers and the editor, whose opinions improved the focus of the manuscript and PhD and Eduardo Zattara for his review of the English grammar.

REFERENCES

Anderson, R. O., & Neumann, R. M. (1996). Length, weight and associated structural indices. In B. R. Murphy, & D. W. Willis (Eds.), *Fisheries techniques*, 2nd ed. (pp. 447–482). Bethesda, Maryland: American Fisheries Society.

BioSonics (2004). *User guide visual analyzer 4* (p. 79). Seattle: BioSonics Inc.

CEAN (Centro de Ecología Aplicada del Neuquén) (2002). *Programa de investigación y manejo integrado de la pesca en el sistema lago Traful*. Informe Final del Área de Ecología Acuática, 33 pp.

Chipps, S. R., & Garvey, J. E. (2007). Assessment of food habits and feeding patterns. In C. S. Guy, & M. L. Brown (Eds.), *Analysis and interpretation of freshwater fisheries data* (pp. 473–514). Bethesda, Maryland: American Fisheries Society.

Ciancio, J. E., & Pascual, M. A. (2006). Energy density of freshwater Patagonian organisms. *Ecología Austral*, *16*, 91–94.

Ciancio, J. E., Pascual, M. A., & Beauchamp, D. A. (2007). Energy density of Patagonian aquatic organisms and empirical predictions based on water content. *Transaction of the American Fisheries Society*, *136*, 1415–1422.

Cowx, I. G. (2000). *Management and ecology of river fisheries* (444 pp). UK: Blackwell Science.

Danie, D. S., Trial, J. G., & Stanley, J. G. (1984). *Species profiles: Life histories and environmental requirements of coastal fish and invertebrates (North Atlantic) - Atlantic Salmon*. U.S. Fish and Wildlife Service FWS/OBS-82/11.22, U.S. Army Corps of Engineers TR EL – 82-4, 19 pp.

Dieterman, D. J., Thorn, W. C., & Anderson, C. S. (2004). *Application of a bioenergetics model for Brown Trout to evaluate growth in southeast Minnesota streams*. Minnesota Department of Natural Resources Investigational Report No 513, 27 pp.

Hanson, P. C., Johnson, T. B., Schindler, D. E., & Kitchell, J. F. (1997). *Fish bioenergetics 3.0 software for Windows®*. University of Wisconsin Sea Grant Institute, Report WISCU-T-97-001, Madison.

Hartman, K. J., & Cox, M. K. (2008). Refinement and testing of brook trout bioenergetics model. *Transaction of the American Fisheries Society*, *137*, 357–363.

Jackson, R., Moffitt, C., & Whelan, G. (2010). History on inland fisheries management in North America. In W. A. Hubert, & M. C. Quist (Eds.), *Inland fisheries management in North America*, 3rd ed. (pp. 1–41). Bethesda, Maryland: American Fisheries Society.

Juncos, R., Beauchamp, D. A., & Vigliano, P. H. (2013). Modeling prey consumption by native and nonnative piscivorous fishes: Implications for competition and impacts on shared prey in an ultraoligotrophic lake in Patagonia. *Transactions of the American Fisheries Society*, *142*, 268–281.

Juncos, R., Milano, D., Macchi, P. J., Alonso, M. F., & Vigliano, P. H. (2011). Response of Rainbow Trout to different food web structures in northern Patagonia: Implications for growth, bioenergetics, and invasiveness. *Transactions of the American Fisheries Society*, *140*, 415–428.

Juncos, R., Milano, D., Macchi, P. J., & Vigliano, P. H. (2015). Niche segregation facilitates coexistence between native and introduced fishes in a deep Patagonian lake. *Hydrobiologia*, *747*(Suppl. 1), 53–67.

Kohler, C. C., & Hubert, W. A. (1999). *Inland fisheries management in North America* (p. 718). Bethesda, Maryland, USA: American Fisheries Society.

Love, R. H. (1977). Target strength of an individual fish at any aspect. *The Journal of the Acoustical Society of America*, *62*(Suppl. 6), 1397–1403.

Macchi, P. J., & Vigliano, P. H. (2014). Salmonid introduction in Patagonia: The ghost of past, present and future management. *Ecología Austral*, *24*, 162–172.

Macchi, P. J., Vigliano, P. H., Pascual, M. A., Alonso, M. F., Denegri, M. A., Milano, D., … Lippolt, G. E. (2008). Historical policy goals for fish management in Northern Continental Patagonia Argentina: A structuring force of actual fish assemblages? In J. L. Nielsen, J. J. Dodson, K. Friedland, T. R. Hamon, J. Musick, & E. Verspoor (Eds.), *Reconciling fisheries with conservation: Proceedings of the Fourth World Fisheries Congress* (pp. 331–348). Bethesda, Maryland: American Fisheries Society, Symposium 49.

Miranda, L. E., & Bettoli, P. W. (2007). Mortality. In C. S. Guy, & M. L. Brown (Eds.), *Analysis and interpretation of freshwater fisheries data* (pp. 229–277). Bethesda, Maryland: American Fisheries Society.

Neumann, R. M., & Allen, M. S. (2007). Size structure. In C. S. Guy, & M. L. Brown (Eds.), *Analysis and interpretation of freshwater fisheries data* (pp. 375–422). Bethesda, Maryland: American Fisheries Society.

Newcomb, T. J., Orth, D. J., & Stauffer, D. F. (2007). Habitat evaluation. In C. S. Guy, & M. L. Brown (Eds.), *Analysis and interpretation of freshwater fisheries data* (pp. 843–886). Bethesda, Maryland: American Fisheries Society.

Nielsen, L. A. (1999). History of inland fisheries management in North America. In C. C. Kohler, & W. A. Hubert (Eds.), *Inland fisheries management in North America* (pp. 3–30). Bethesda, Maryland: American Fisheries Society.

Pascual, M. A., Cussac, V. E., Dyer, B., Soto, D., Vigliano, P. H., Ortubay, S., & Macchi, P. J. (2007). Freshwater fishes of Patagonia in the 21st century after a hundred years of human settlement, species introductions, and environmental change. *Aquatic Ecosystem Health and Management*, *10*(Suppl. 2), 1–16.

Pascual, M. A., Macchi, P. J., Urbanski, J., Marcos, F., Riva Rossi, C., Novara, M., & Dell'Arciprete, P. (2002). Evaluating potential effects of exotic freshwater fish from incomplete species presence-absence data. *Biological Invasions*, *4*, 101–113.

Pinkas, L., Oliphant, M. S., & Iverson, I. L. K. (1971). *Food habits of albacore, bluefin tuna, and bonito in California waters*. California: Department of Fish and Game, Fisheries Bulletin No 152, 105 pp.

Pope, K. L., & Kruse, C. G. (2007) Condition. In: Guy C. S & M. L. Brown (Eds.) *Analysis and interpretation of freshwater fisheries data*. Bethesda, Maryland: American Fisheries Society, pp. 423–471

Rand, P. S., Stewart, D. J., Seelbach, P. W., Jones, M. L., & Wedge, L. R. (1993). Modeling Steelhead population energetics in Lakes Michigan and Ontario. *Transactions of the American Fisheries Society*, *122*, 977–1001.

Rechencq, M. (2012). *Patrones de distribuciones espaciales y temporales de la comunidad de peces de un lago andino-patagónico y su relación con la heterogeneidad espacial del hábitat*. PhD Thesis. Bariloche, Argentina: National University of Comahue, 149 pp.

Rechencq, M., Sosnovsky, A., Macchi, P. J., Alvear, P. A., & Vigliano, P. H. (2011). Extensive diel fish migrations in a deep ultraoligotrophic lake of Patagonia Argentina. *Hydrobiologia*, *658*, 147–161.

Rechencq, M., Vigliano, P. H., Macchi, P. J., & Lippolt, G. E. (2014). Fish distribution patterns and habitat availability in lakes Moreno Este and Moreno Oeste, Patagonia, Argentina. *Limnologica*, *49*, 73–83.

Schöener, T. W. (1970). Non-synchronous spatial overlap of lizards in patchy habitats. *Ecology*, *51*, 408–418.

Slipke, J. W., & Maceina, M. J. (2001) *Fishery analyses and simulation tools (FAST 2.0)*. Alabama, USA: Department of Fisheries and Allied Aquacultures, Auburn University, 156 pp.

Stanley, J. G., & Trial, J. G. (1995) *Habitat suitability index models: non-migratory freshwater life stages of Atlantic Salmon*. USDI/NBS Report No 3, 18 pp.

Vigliano, P. H., & Alonso, M. F. (2007). Salmonid introductions in Patagonia: A mixed blessing. In T. M. Bert (Ed.), *Ecological and genetic implications of aquaculture activities* (pp. 315–331). Nordstadt, The Netherlands: Springer.

Vigliano, P. H., Alonso, M. F., Denegri, M. A., García Asorey, M. I., Lippolt, G. E., Macchi, P. J., & Navone, G. (2002). *Evaluación de los Recursos Ícticos del Lago Traful: Modulos I y II, Informe final*. Cipolletti, Argentina: Autoridad Interjurisdiccional de las Cuencas de los Ríos Limay, Neuquén y Negro, 150 pp.

Vigliano, P. H., Alonso, M. F., Macchi, P. J., Denegri, M. A., García Asorey, M. I., Lippolt, G. E., & Alvear, P. A. (2008). Gill net and hydroacoustic fish resource evaluation of an ultraoligotrophic lake in Northern Patagonia, Argentina. In J. L. Nielsen, J. J. Dodson, K. Friedland, T. R. Hamon, J. Musick, & E. Verspoor (Eds.), *Reconciling fisheries with conservation: Proceedings of the Fourth World Fisheries Congress* (pp. 1725–1747). Bethesda, Maryland: American Fisheries Society, Symposium 49.

Vigliano, P. H., Beauchamp, D. A., Milano, D. A., Macchi, P. J., Alonso, M. F., García Asorey, M. I., … Barriga, J. P. (2009b). Quantifying predation on Galaxiids and other native organisms by introduced rainbow trout in an ultraoligotrophic lake in northern Patagonia, Argentina: A bioenergetics modeling approach. *Transaction of the American Fisheries Society*, *138*, 1405–1419.

Vigliano, P. H., Lippolt, G. E., Juncos, R., Macchi, P. J., Alonso, M. F., Denegri, M. A., Rechencq, M., & Hougham, V. (2009a). *Evaluación y modelado de las poblaciones de peces del lago Traful con miras al desarrollo de una pesquería recreacional distintiva Informe final*. Cipolletti, Argentina: Autoridad Interjurisdiccional de las Cuencas de los Ríos Limay, Neuquén y Negro, 150 pp.

Wallace, R. K. (1981). An assessment of diet-overlap indexes. *Transactions of the American Fisheries Society*, *110*, 72–76.

Wootton, R. J. (1990). *Ecology of teleost fishes* (p. 404). London: Chapman and Hall.

How to cite this article: Rechencq M, Vigliano PH, Lippolt GE, et al. Modelling and management options for salmonid sport fisheries: A case study from Patagonia, Argentina. *Fish Manag Ecol*. 2017;00:1–14. doi:10.1111/fme.12208.