Project Completion Report

Project Title: Improving Hatchery Techniques of Lumpfish (*Cyclopterus lumpus*) for Use as a Cleaner Fish to Control Sea Lice in Atlantic Salmon and Steelhead Trout Net Pens

Subaward # Z5111201
Grant # 2018-38500-28885

INSTRUCTIONS: *All investigators prepare and submit their report to the Project Coordinator at least two weeks prior to the due date.* The Project Coordinator will edit all reports into one final report to be submitted to the Director, NRAC. Following revisions/approval, the Project Coordinator will provide the approved Project Completion report to the Director of NRAC in hard copy and electronically. Format of individual and combined reports should adhere to the following headings with a separation page between parts I and II.

PROJECT CODE: 18-03 **SUBCONTRACT/ACCOUNT NO:**

PROJECT TITLE: Improving Hatchery Techniques of Lumpfish (*Cyclopterus lumpus*) for Use as a Cleaner Fish to Control Sea Lice in Atlantic Salmon and Steelhead Trout Net Pens

DATES OF WORK: 1/1/2019- 12/31/2021

PARTICIPANTS: Funded cooperating personnel and institutions, agencies, and business entities including extension liaison(s) and non-funded collaborators.

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REASON FOR TERMINATION: Indicate objective(s) completed, funds terminated, or other specific reason for project termination.

All objectives that could be completed during the 3-year time frame were completed.

PROJECT OBJECTIVES: List objectives as written in approved proposal.

Objective 1: Optimizing lumpfish hatchery techniques for early life history stages.
Ho 1: Declumping the naturally, sticky lumpfish eggs will increase survival and hatching.
Ho 2: Eliminating live feed for newly-hatched lumpfish larvae will not affect their growth and survival.

Objective 2: Optimizing lumpfish larval and juvenile nutrition parameters through protein to energy studies to identify protein and fat levels that improve growth and survival.
Ho 3: Varying protein and fat levels will affect the growth and survival of larval lumpfish.
Ho 4: Varying protein and fat levels will affect the growth and survival of juvenile lumpfish.

Objective 3: Conveying research findings to stakeholders by developing lumpfish husbandry guides and standard operating procedures and holding workshops.

ANTICIPATED BENEFITS: State how the project will benefit the aquaculture industry either directly or indirectly.

The overall goal of this project is to address existing lumpfish culture gaps at the hatchery, provide rearing protocols and guidelines that enable the development of a Northeast lumpfish hatchery, and provide the salmon and steelhead trout industries with feasible techniques so that sea lice mitigation is less costly and more sustainable.

PRINCIPAL ACCOMPLISHMENTS: Summarize in a concise form the findings for each objective for the duration of the project. Measurement data are to be given in SI units. However, to minimize confusion, a dual system of measurement may be used to express results.

Objective 1 findings:
1) Wild lumpfish populations have shifted or are not as abundant as they used to be in the southwestern Gulf of Maine.
2) Capturing post-spawning lumpfish via bottom trawl is not a viable method to build a captive broodstock population.
3) Post-spawning, female lumpfish can be found at depths of 110-120 m on or near muddy bottoms.
4) Collecting and on-growing wild juveniles, which have higher survival and are fairly easy to wean onto pellets, and using hatchery-reared fish may be the most effective way to build a captive broodstock.
5) Live feed is not necessary for culturing larval lumpfish. In our study, while there was no significant difference in survival between treatments, there was a trend towards higher survival when fish were not fed live feed.

6) If lumpfish are reared in flat bottomed tanks, using living feed is recommended to reduce tank cleaning time during the larval period when only live feed is being used and fish are most fragile. If eliminating live feed, false-bottom tanks help reduce cleaning time and, likely as a result, reduced fish cleaning gear interactions, promoting higher fish survival.

Objective 2 findings:
1) Adequate commercial larval lumpfish diets are available.
2) Because larval lumpfish growth rates are so fast, larval diets make up only a small component of hatchery costs (i.e., small volume of larval feeds used relative to juvenile diets due to fast fish growth).
3) Generally, juvenile lumpfish have good growth results when fed a high protein (50-55%), lower lipid (10-20%) diet, especially when compared to fish fed a salmon diet (lower protein and higher lipid).
4) The most practical solution for feeding juvenile lumpfish is using the commercial diet we tested since, generally, it was as good as the experimental diets we evaluated.
5) Lumpfish have poorer growth results (slower growth, higher FCR) when fed a commercial salmon feed providing some insight into what to expect of lumpfish in the farm if they consume the salmon feed.

IMPACTS: In concise statements (possibly a bulleted list) indicate how the project has or will benefit the aquaculture industry either directly or indirectly and resulting economic values gained (where appropriate).

- Through our first round of hatchery studies, we gained a better understanding of lumpfish culture techniques and nutritional requirements.
- Through the creation of the US Lumpfish Consortium, community connectivity has been strengthened between research organizations/academia and aquaculture industries.
- Lumpfish production at US research facilities (mainly UNH and UME CCAR) has increased.
- A captive reared broodstock program at the USDA and CCAR was initiated to support industry and public research efforts.
- The first commercial US lumpfish hatchery is under construction and expected to be operational in spring 2022.

RECOMMENDED FOLLOW-UP ACTIVITIES: State concisely how future studies may be structured.

Future studies could focus on Objective 1 studies as we were not able to evaluate if declumping lumpfish eggs has a positive benefit to hatching success. Because of space restrictions in our research facilities, it would be beneficial for future studies to scale up in size (tank volume, fish numbers) and test the most promising combinations to simulate commercial hatchery conditions more closely.

SUPPORT: Use the format in the table below to indicate NRAC-USDA funding and additional other support, both federal and non-federal, for the project. Indicate the name of the source(s) of other support as a footnote to the table.

YEAR	NRAC-USDA FUNDING	OTHER SUPPORT					TOTAL SUPPORT
		UNIVER-SITY	INDUSTRY	OTHER FEDERAL	OTHER	TOTAL	
2019	100,000						100,000
2020	100,000						100,000
2021							
TOTAL	200,000						200,000

PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED: List under an appendix with the following subheadings: *Publications in Print*; *Manuscripts*; and *Papers Presented*. For the first two subheadings, include journal articles, popular articles, extension materials, DVDs, technical reports, theses and dissertations, etc. using the format of the Transactions of the American Fisheries Society (example below). Under *Papers Presented* subheading include the authors, title, conference/workshop, location, and date(s). Example of Transactions of the American Fisheries Society citation format: Billington, N., R. J. Barrette, and P. D. N. Hebert. 1992. Management implications of mitochondrial DNA variation in walleye stocks. North American Journal of Fisheries Management 12:276-284.

Publications in Print

NOTE: many of these publications highlight lumpfish research that was in part supported by these NRAC funds.

Gonzalez, R. 2020. Group lays groundwork for commercial lumpfish production in the US. Aquaculture North America, April/May 2020, p.4.

Mayer, L. 2020. Concerns raised over cleanerfish welfare. Aquaculture North America, July/August 2020, p. 4. https://mydigitalpublication.com/publication/?m=53591&i=664607&p=4

Wright, L. 2020. Lumpfish hold potential for managing sea lice infestations at fish farms: UNH researchers aim to boost U.S. production of Atlantic salmon and steelhead trout. UNH NH Agriculture Experiment Station. https://colsa.unh.edu/nhaes/article/2020/06/lumpfish (reprinted by Concord Monitor and Seacoast Online, June, 29, 2020).

Hill, S. 2020. US consortium wants to increase lumpfish production in New England. Seafood Source, June 10, 2020.

Brooks, D. 2020. Delightfully named lumpfish might boost caged salmon production. Concord Monitor, June 29, 2020. https://granitegeek.concordmonitor.com/2020/06/29/delightfully-named-lumpfish-might-boost-caged-salmon-production/

Staff Writer. 2020. UNH researchers use cleanerfish to fight sea lice helping salmon and trout production. Seacoast Online, July 3, 2020. https://www.seacoastonline.com/news/20200703/unh-researchers-use-cleanerfish-to-fight-sea-lice-helping-salmon-and-trout-production

Pietrak, M.R., and Peterson, B.C. 2021. Genetic and other innovative strategies to reduce sea lice. Theme-based Special Session of the Council of North Atlantic Salmon Conservation Organization (NASCO), Virtual Meeting May 27, 2021. (invited symposium paper)

Record, J. 2021. Liking lumpfish: grad student's research goes viral. UNH Today (3/15/2021). https://www.unh.edu/unhtoday/2021/03/liking-lumpfish

Goethel, E. 2021. Lumpfish are more than just a funny looking fish. Portsmouth Herald (6/30/21)

Doherty, M. B. 2021. The presence of sea lice on steelhead trout at a marine farm in NH waters and the utilization of lumpfish as a biological delouser. Master's Thesis, Department of Biological Sciences, University of New Hampshire, Durham, NH, 111 p.

Spada, N. N. 2021. Improving larval and juvenile lumpfish, *Cyclopterus lumpus*, aquaculture: nutrition and growing conditions. Master's Thesis, Department of Biological Sciences, University of New Hampshire, Durham, NH, 133 p.

Fairchild, E. A., M. R. Pietrak, and G. S. Burr. 2021. Lumpfish Hatchery Handbook. Northeastern Regional Aquaculture Center. Publication #301-2021. Maryland, 43 pages.

Manuscripts

Spada, N. N., E. A. Fairchild, M. Pietrak, G. Burr, and J. Trushenski. (in prep) The effect of protein and lipid concentrations on the growth, survival, and aggression of juvenile lumpfish (*Cyclopterus lumpus*). Aquaculture.

Papers Presented and Oral Presentations:

Fairchild, E. A. 2019. Morning Panel: Experimental and Technologically Feasible Species - Lumpfish. "Status of Marine Fish Species for US Aquaculture" Session, Aquaculture America 2019. The annual meeting of the World Aquaculture Society, March 8-11, 2019, New Orleans, LA. (invited panelist)

Fairchild, E. A. 2019. The cleanerfish conundrum: initiating a lumpfish program in the US. UNH Sustainable Fisheries and Aquaculture Club Seminar, Feb. 20, 2019, Durham, NH. (invited speaker)

Fairchild, E. A. 2020. The status of lumpfish production in the US. Aquaculture America 2020, February 9-12, 2020, Honolulu, HI. (invited speaker)

Chambers, M. and E. A. Fairchild. 2020. Advancing US marine aquaculture at the University of New Hampshire. Aquaculture America 2020, February 9-12, 2020, Honolulu, HI. (invited speakers)

Pietrak, M.R., Burr, G.S., Peterson, B.C. Developing a lumpfish research program at the National Cold Water Marine Aquaculture Center. Aquaculture America 2020, February 9-12, 2020, Honolulu, HI. (invited speaker)

Fairchild, E. A. 2020. US Lumpfish Consortium: promoting cleanerfish in salmonid farming. AFS Atlantic International Chapter October meeting, October, 24, 2020; live Zoom presentation.

Doherty, M. 2021. Aquaculture of the lumpfish, *Cyclopterus lumpus*, and implementation as a cleanerfish. University of New Hampshire Marine Docents Seminar Series, March 2, 2021; live Zoom presentation.

Doherty, M. 2021. UNH Grad School: lumpfish research, aquaculture, and a career in marine science. Troy Howard Middle School career day talk, March 26, 2021; live Zoom presentation and Q&A.

Doherty, M. 2021. Marine Bio Spotlight: Lumpfish research and my path as a marine biologist. Gulf of Maine Research Institute Scientist to go program, April 8, 2021; live Zoom presentation and Q&A.

Doherty. M. 2021. An analysis of sea lice in an experimental NH aquaculture station, and the use of lumpfish as a lice mitigation strategy. UNH Graduate Research Conference, April 19, 2021. https://media-gallery.unh.edu/media_submission/500/

Doherty, M. 2021. Parasitic sea lice populations in an experimental salmonid aquaculture system in NH waters and using lumpfish as a possible solution. UNH School of Marine Science and Ocean Engineering Graduate Research Symposium, May 5, 2021; live Zoom presentation.

Fairchild, E. A. 2021. Increasing domestic aquaculture production with environmentally friendly technology: promoting cleanerfish in salmonid farming. Biology Department Spring Seminar Series, College of Charleston, March 8, 2021; live Zoom presentation. (invited speaker)

Spada, N. 2021. Quantifying the impacts on growth in juvenile cultured lumpfish: nutritional and density dependent conditions. UNH Graduate Research Conference, April 19, 2021. https://media-gallery.unh.edu/media_submission/513/

Spada, N. 2021. Nutritional and density dependent effects on the growth of juvenile culture lumpfish. UNH School of Marine Science and Ocean Engineering Graduate Research Symposium, May 5, 2021; live Zoom presentation.

Pietrak, M.R., and Peterson, B.C. 2021. Genetic and other innovative strategies to reduce sea lice. Theme-based Special Session of the Council of North Atlantic Salmon Conservation Organization (NASCO), Virtual Meeting May 27, 2021. (invited speaker)

Doherty, M. B. 2021. The presence of sea lice on steelhead trout at a marine farm in NH waters and the utilization of lumpfish as a biological delouser. UNH Master's defense seminar, July 28, 2021; live Zoom presentation.

Fairchild, E. A. 2021. The use of cleanerfish in salmonid farming: why not transfer this environmentally-friendly technology to boost domestic seafood production? NOAA Northwest Fisheries Science Center Monster Jam Seminar Series, November 17, 2021; live Zoom presentation advertised on OneNOAA Science Seminars listserv. (invited speaker)

Spada, N. N. 2021. Improving Larval and Juvenile Lumpfish, *Cyclopterus lumpus*, Aquaculture: Nutrition and Growing Conditions. UNH Master's defense seminar, November 29, 2021; live Zoom presentation.

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PART II

TECHNICAL ANALYSIS AND SUMMARY: Describe the work undertaken and results obtained for each objective. Major results should be presented in detail, including graphs, charts, figures, photomicrographs or other presentations. Methodology should be briefly described and statistical analyses and significance should be included where appropriate. This section of the report should be written with style similar to scientific publication. Reports previously or currently prepared for publication may be submitted as part of this section.

Objective 1: Optimizing lumpfish hatchery techniques for early life history stages.
Ho 1: Declumping the naturally, sticky lumpfish eggs will increase survival and hatching.

We were unable to complete this objective because we did not have access to pre-spawning mature lumpfish during this project timeline.

UNH situation: In the past, we've had no trouble procuring wild, pre-spawning, adult lumpfish, usually in Feb-April, by working with commercial fishermen. In 2019, NH groundfishermen and lobstermen again agreed to collect lumpfish for a fee. If any lumpfish were incidentally caught during their normal fishing activities, the fishermen set the lumpfish aside in live tanks, contacted us, and someone met them at the dock to transfer the fish back to the UNH Coastal Marine Lab (CML) in a truck with an oxygenated, seawater tank. However, in 2019, only 2 fish were caught in the spring and none were in pre-spawning condition, thus, we did not have access to pre-spawning lumpfish. Another 17 adult lumpfish were caught in summer; the majority (16) were captured by bottom trawl gear in June and one fish by lobster gear in July. In the CML, the fish were held in ambient flow-through seawater tanks on a natural photoperiod. Very few fish survived long-term in captivity. Most died within the week post-capture, likely due to the multiple stressors incurred from bottom trawling and temperature shock. (Post mort dissections revealed that the majority of fish were post-spawning females.) When this became apparent, we decided it was in the best interest of the wild lumpfish population to curtail collections until we could ensure a higher probability of survival. Further, it was very challenging getting the fish to feed in captivity. We were able to coax a handful of fish to feed finally by offering frozen krill and, after several months, were able to transition them onto a pellet. Only three fish (2 females, 1 male) survived to the 2020 spring spawning season, but the male died before the females ripened, preventing us from attempting to strip spawn fish for year 2 of the project. In order to be able to make progress on the remaining research objectives, we imported fertilized lumpfish eggs from Memorial University of Newfoundland in August 2019.

In 2020 (year 2), we were not able to work with commercial fishermen or attempt our own wild fish capture methods due to restrictions from UNH's COVID-19 policies. All research was reduced to only maintaining animal populations during March-June; no experiments were allowed nor were new animals allowed to be brought in. For this reason, the only option we had for 2020 fish was to import fertilized lumpfish eggs again from Memorial University in August 2020.

While not the broodstock outcome we had hoped for, we have become aware that: 1) wild lumpfish populations have shifted or are not as abundant as they used to be in the southwestern Gulf of Maine; 2) capturing post-spawning lumpfish via bottom trawl is not a viable method to build a captive broodstock population; 3) post-spawning, female lumpfish can be found in 110-119 meter water on or near muddy bottoms. Going forward, we believe collecting and rearing wild juveniles, which have higher survival and are fairly easy to wean onto pellets, and using hatchery-reared fish will be the most effective way to build a captive broodstock. This information has been shared with other US lumpfish collaborators and, as a result, collecting and on-growing wild age 0 fish is how UME CCAR is establishing their captive lumpfish populations.

NCWMAC situation: When the NCWMAC lumpfish facilities closed for construction in 2019, the existing broodstock was moved next door to UME CCAR. Since then, the broodstock, along with wild fish collected as young-of-the-year, have had relatively poor spawning success thus far; strip spawning did not yield enough viable fertilized, eggs to use.

Ho 2: Eliminating live feed for newly-hatched lumpfish larvae will not affect their growth and survival.

UNH trial: This experiment was not conducted at UNH. Because we used eggs from Newfoundland for this project, the newly hatched lumpfish reared were about 6 months out of synch with the native NH lumpfish populations and required colder water than the ambient temperature water available. For this reason, it was essential to rear the larval lumpfish in a chilled recirculating system. At the UNH Coastal Marine Lab, we found that it is not feasible to conduct experiments with newly-hatched lumpfish in our small experimental RAS tanks; the fish are flushed out of the tanks.

NCWMAC trial: The first feeding study was completed at the NCWMAC to examine survival and growth of larval lumpfish fed live feed (enriched *Artemia*) and then weaned onto a dry diet compared to larvae started directly on commercial micro-diets, as well as the effects of tank bottom type (solid, false bottom). The fish hatched on Aug. 25th and 26th, 2020 and were randomly divided into 12 tanks (solid bottom tanks were 10L and the false bottom tanks were 12 L) on Aug. 26th with 650-700 newly hatched fish per tank (solid bottom tanks were stocked at ~67 fish/L and the false bottom tanks were stocked at ~ 56 fish/L). Two feed treatments (live feed, micro-diet) were tested with two tank treatments (solid bottom, false bottom) in triplicate. Fish in the live feed treatment were weaned onto micro-diets by 36 days post hatch (dph). The remaining 6 tanks were only fed micro-diets. Total time spent feeding and cleaning each treatment was recorded as well as final fish growth and survival. The study was completed at the end of October 2020 when fish were approx. 2 months old.

The proportion of fish that survived to 55 dph were arcsin transformed and analyzed in a two-way ANOVA (Prism 9). There were no significant differences between treatments (p=0.3659) or within treatment groups (Tank type p=0.1584; Feed type p=0.0553; Table 1).

Table 1. Average percent survival for each tank and feed type (n=3, except micro-diet in solid bottom n=2). There were no significant differences between treatments (p=0.3659, 2-way ANOVA)

	Solid Bottom	False Bottom	Overall
Micro-diets	26.4%	59.2%	46.1%
Live feed	13.3%	18.6%	15.9%
Overall	18.5%	38.9%	

Growth data are not included as researchers were concerned about the accuracy of the wet weights of such small fish.

On average cleaning the solid bottom tanks took 26 minutes to clean 6 tanks, while the false bottom tanks took 9 minutes to clean 6 tanks. In addition, cleaning was required twice as often in solid bottom tanks as in the false bottom tanks. When trying to siphon the solid bottom tanks, larval lumpfish do not move out of the way and often get siphoned up, causing stress, possible bodily damage, and loss of some normal healthy fish. Two strategies to minimize fish loss were tried: using screens on the end of the siphon and siphoning into a screen to try and catch live fish so they could be returned to the rearing tank. While somewhat successful, neither strategy was 100% effective. The use of false bottom tanks not only reduced the frequency of cleaning required compared to using traditional flat bottom tanks, but the cleaning was likely less stressful to the fish. When cleaning the false bottom tanks, the end of the siphon could be used to either push the small amount of accumulated feed through the screen or water could be gently run through it in reverse to essentially hose the uneaten feed through the bottom into the larger surrounding tank. Then the false bottom tank was moved to another location in the larger outer tank and the feed was siphoned up with little to no interaction with the fish throughout the whole process.

Overall, either feeding newly hatched lumpfish *Artemia* or skipping live feed and providing them with only micro-diets are both feasible ways for rearing larval lumpfish. When using traditional flat bottom tanks, use of *Artemia* is preferred given the need to not clean as often when feeding only *Artemia* in the beginning compared to the daily cleaning when only feeding micro-diets.

Objective 2: Optimizing lumpfish larval and juvenile nutrition parameters through protein to energy studies to identify protein and fat levels that improve growth and survival.
Ho 3: Varying protein and fat levels will affect the growth and survival of larval lumpfish.

This study was conducted by UNH in Year 1 (fall 2019). Experimental larval diets were manufactured by the USDA and shipped to the USDA NCWMAC. They were then spilt in half and half was sent to UNH for running trials. The diets (protein/lipid) tested were as follows:

- Diet 1: 50/10
- Diet 2: 50/15
- Diet 3: 50/20
- Diet 4: 55/10
- Diet 5: 55/15
- Diet 6: 55/20
- Diet 7: 59/10
- Diet 8: 59/15
- Diet 9: 59/20
- Diet 10: (Skretting Gemma Wean 0.3/0.5 mm mix)

We included Diet 10, as a control, as it is the main commercial larval lumpfish diet available and what the fish had been fed prior to the start of the experiment.

UNH trial: The larval diet study was conducted for <1 month, from Nov. 4-24, 2019. A recirculating system was used to evaluate the 10 experimental diets in triplicate using 3L tanks. Each tank was stocked with 100 fish, batch weighed, and mean fish weight averaging 0.10 g/tank. Fish were hand fed the experimental diets 5 x daily (800, 1000, 1200, 1400, 1600) at 7% body weight, and the amount of feed fed/day was recorded (and adjusted based on daily mortality). Temperature and salinity were monitored, and all mortalities removed and counted daily. Fish were batch sampled (g) bimonthly, but the growth portion of the experiment only lasted 2 weeks due to poor survival.

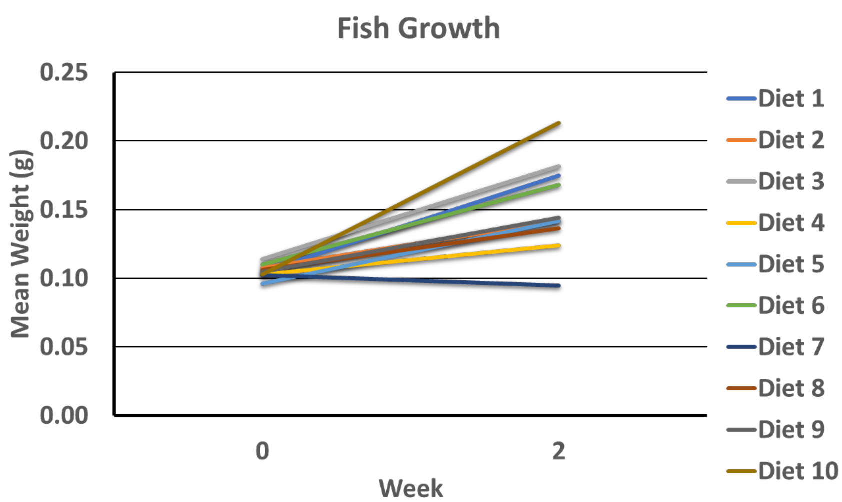

Figure 1. Mean weights of the larval lumpfish over time in each diet treatment.

After 2 weeks, mean fish growth ranged from 0.09 to 0.21 g/treatment (Figure 1), but this was less meaningful considering the poor survival in fish in all experimental diet treatments.

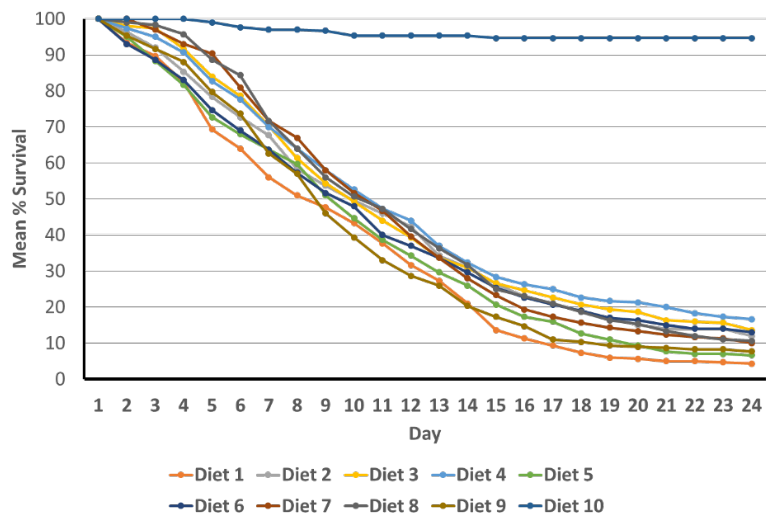

Figure 2. Mean survival of the larval lumpfish over time in each diet treatment.

Fish survival dropped precipitously in all treatments except the control (diet 10; Figure 2). Thinking water quality may be contributing to the high mortality, at day 16, we switched the recirculating system to flow-through. Survival continued to decline so at day 21, we switched out the 'baby baffles' to 'regular' baffles to increase water flow and protein skimming capabilities. Neither seemed to have much influence on decreasing mortality. The fish fed the control diet (diet 10), not only had the greatest growth in the 2-week period, but over the 24-day period, had very high survival. Survival in the 3 control diet tanks ranged from 78 to 98 %, with a mean survival of 87 ± 5%.

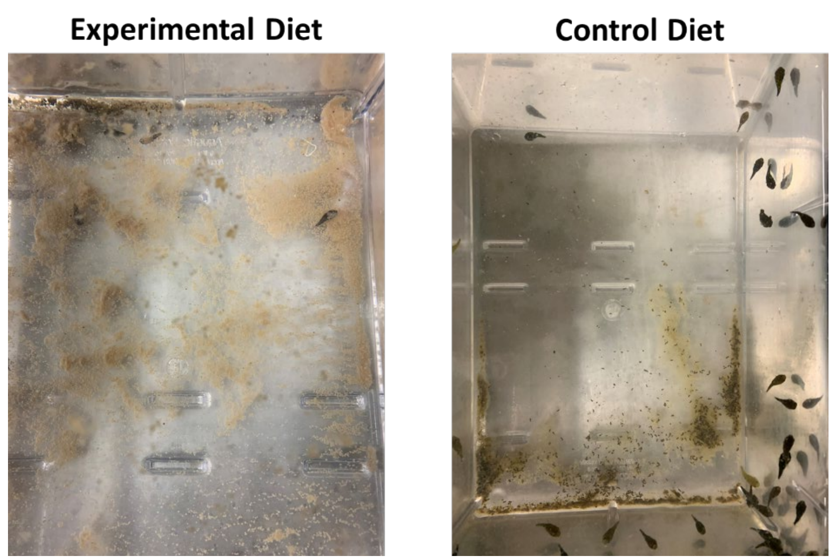

Figure 3. View looking down into tank of one of the experimental diets and the control diet. Note how the experimental diet dissolved into a slimy layer whereas the control diet remained intact.

Upon closer examination, the experimental diets were powdery and dissolved into a fungus-like layer on the bottom of the tanks, whereas the control diet remained more intact, even as it settled out to the tank bottom (Figure 3). We concluded that due to the experimental diet manufacturing process which utilized a cold pellet instead of an extruded pelleting process that the commercial feed uses, resulted in decreased pellet stability.

NCWMAC trial: This study was not run at the USDA as their lumpfish facilities were closed for mechanical reasons in fall/winter 2019, and their new, current facility (in use now) was not ready at the time the larval fish were available.

We did not pursue larval experimental diets further for 2 reasons: 1) adequate commercial larval lumpfish diets are available, and 2) because larval lumpfish growth rates are so fast, larval diets make up only a small component of hatchery costs (i.e., small volume of larval feeds used relative to juvenile diets due to fast fish growth).

Ho 4: Varying protein and fat levels will affect the growth and survival of juvenile lumpfish.

This study was conducted at both UNH and the USDA NCWMAC during summer 2020. Based on the insight we had with the larval diet experiment, it was recommended that we focus on higher protein diets, so we eliminated the 40% and 45% protein experimental diets. Instead, we added two commercially available and higher protein diets to the study.

The experimental diets were made by the USDA Aquaculture Research Service at the Bozeman Fish Technology Center, in Bozeman, Montana in February 2019, shipped to the USDA NCWMAC, and were freezer stored when not in use. The experimental diets were made by grinding all ingredients to <200 µm in an air-swept pulverizer. The diets were then put into an extruder at 127 °C for about 25 sec. These pellets were then put into a pulse bed dryer at 102 °C for 20 min with a 10 min cooling period following. A vacuum-coater was then used to top-coat all oil onto the pellets. The experimental diets (protein/lipid) tested were as follows:

- Diet 1: 50/15
- Diet 2: 55/10
- Diet 3: 50/20
- Diet 4: 55/20
- Diet 5: 55/15
- Diet 6: 50/10
- Diet 7 (Biotrout): 47/24
- Diet 8 (Europa): 55/15

We included Diet 8, Europa (Skretting) as a control, as it is the main commercial juvenile lumpfish diet available and what the fish had been fed prior to the start of the experiment. Diet 7, BioTrout diet (Bio-Oregon), was included to understand what the effects to lumpfish would be post-stocking into salmonid farms if the lumpfish eat the salmonid diet (instead of a lumpfish diet or sea lice).

UNH trial: Two juvenile diet trials were conducted for 10 weeks each at UNH.

Methods

Growth and survival of juvenile Lumpfish fed diets differing in protein/lipid concentrations and protein sources were evaluated at the CML in two separate experiments, herein referred to as "Trial 1" and "Trial 2." Trial 1 took place over the course of 10 weeks in which six experimental diet treatments were tested in quadruplicate, and two commercially available diets (Skretting Europa and BioTrout) were tested in triplicate (Tables 2-5). All diets were 2.0 mm in size.

Based on the results from Trial 1, three diets resulting in lower fish growth metrics (overall percent growth, growth rate, weight gain, and specific growth rate) were eliminated. Prior the start of Trial 2, the four experimental diets and one commercially available diet were tested by the USDA NCWMAC to ensure that they had not gone bad. Since the eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) levels had not decreased since the diets were manufactured, the diets were deemed safe for testing and then retested with juvenile Lumpfish in triplicate in Trial 2 over the course of eight weeks (Tables 2-5).

Fish from the general population of cultured, juvenile Lumpfish reared at the CML were graded to the desired size and stocked into 10 L aquaria in a flow-through, ambient temperature and salinity seawater system, exposed to a 12-hour light: 12-hour dark photoperiod (Figure 4). Fish in both trials were fed at 3 % body weight (based on the total weight of the tank), over the course of five feedings per day (8am, 10am, 12pm, 2pm, and 5pm). All fish were sampled biweekly for growth and aggression. Growth was measured by taking the wet weights of each individual to the nearest 0.1 g. Fish aggression was tabulated using a scale from 0 to 5, with 0 representing a fish with an undamaged caudal fin, and 5 a fish with severe damage to the caudal peduncle. Mortalities were recorded, weighed, scored for aggression, and removed daily. Excess feed in the tanks was removed via siphons as needed. Water temperature and salinity were measured daily (Figures 5 and 6).

Data Analysis:

All data were analyzed using Excel 2019 and JMP Pro 15. Overall percent growth, weight gain, specific growth rates (SGR), and feed conversion ratios (FCR) were calculated for each trial using the following formulas:

Overall percent growth = ((Final Weight – Original Weight)/ Original Weight) x 100 %
Weight gain = Final Weight – Initial Weight
SGR = (ln(Final Weight) – ln(Initial Weight))/ Days Tested
FCR = Total Amount Fed/ (Final Total Tank Weight – Initial Total Tank Weight)

One-way ANOVAs and Tukey's tests were used to compare the mean percent growth, mean growth rates, mean weight gain, mean SGR, and mean FCR between the treatments overall. Chi-squared tests were used to compare mean occurrence of fin nips between the treatments.

Figure 4. The experimental, flow-through seawater system used in both diet trials.

Table 2. The testing parameters used for each of the diet trials.

Parameter	**Trial 1**	**Trial 2**
Testing Period	5/18/20 – 6/27/20	3/27/21 – 5/12/21
Initial Fish Size ± 1 s.d. (g)	8.54 ± 1.10	8.39 ± 1.35
Number of Treatments	8	5
Body Weight/Feed Percentage (%)	3	3
Temperature Range (°C)	8-19	4-11
Salinity Range (ppt)	33-36	27-33
Number of Fish per Tank	15	10
Initial Fish Age (days post hatch)	251	198
Initial Stocking Density ± 1 s.d. (g/L)	12.81 ± 0.51	8.39 ± 0.20

Table 3. The protein/lipid concentrations and protein source for each of the diet treatments.

Diet	**Protein/Lipid Concentration (%)**	**Trial 1**	**Trial 2**
1	50/15	Tested	Omitted
2	55/10	Tested	Tested
3	50/20	Tested	Tested
4	55/20	Tested	Tested
5	55/15	Tested	Tested
6	50/10	Tested	Omitted
7	47/24 (BioTrout)	Tested	Omitted
8	55/15 (Skretting Europa)	Tested	Tested

Table 4. The dietary formulation and composition, as percent of the diet dry weight, of the experimental diets (1-6) used in both Trial 1 and 2. Because complete formulation of the commercial diets tested (7 and 8) is proprietary information, only diet ingredients (not quantities) are known. All diets are considered to be nutritionally complete, but some information (like quantities) is not provided by the diet manufacturers.

Diet	**4**	**5**	**2**	**3**	**1**	**6**	**7***	**8****
Protein/Lipid Concentration (%)	55/20	55/15	55/10	50/20	50/15	50/10	47/24	55/15
Ingredient (% of diet dry)								
SeaPro 75, Bio-Oregon Proteins	30.00	30.00	30.00	27.27	27.27	27.27		
Chicken 42 - ADF	20.00	20.00	20.00	18.18	18.18	18.18		
Squid meal	5.28	5.28	5.28	4.80	4.80	4.80		
Blood meal-AP301	3.00	3.00	3.00	2.73	2.73	2.73		
Menhaden fish oil	11.37	6.38	1.39	12.04	7.05	2.06	Present	Present
Wheat gluten meal	5.02	4.08	3.14	2.77	1.80	0.83	Present	
Wheat flour	18.50	24.41	30.34	24.38	30.31	36.25	Present	Present
Lecithin - Yelkinol AC dry lecithin	3.00	3.00	3.00	3.00	3.00	3.00	Present	
Stay-C 35	0.15	0.15	0.15	0.15	0.15	0.15		
Vitamin premix ARS 702	1.00	1.00	1.00	1.00	1.00	1.00	Present	Present
Monocalcium Phosphate	1.10	1.10	1.10	1.50	1.50	1.50		
Choline Cl 50%	1.00	1.00	1.00	1.00	1.00	1.00	Present	Present
DL-Methionine	0.00	0.00	0.00	0.11	0.12	0.13	Present	
Lysine HCl	0.00	0.00	0.00	0.38	0.39	0.39		
Threonine	0.00	0.00	0.00	0.09	0.10	0.11		
Taurine	0.50	0.50	0.50	0.50	0.50	0.50		
Trace mineral premix ARS 1440	0.10	0.10	0.10	0.10	0.10	0.10	Present	Present
Sum with oil:	100.00	100.00	100.00	100.00	100.00	100.00		

Formulated nutrient content (% diet dry weight basis)								
Crude Protein	55.00	55.00	55.00	50.00	50.00	50.00		
Crude Fat	20.00	15.00	10.00	20.00	15.00	10.00		
Digestible protein	52.17	52.02	51.88	47.25	47.11	46.96		
Digestible energy (cal/g)	5198	4877	4556	5020	4698	4376		
Total Phosphorus	0.86	0.87	0.87	0.89	0.90	0.90		
Available phosphorus	0.55	0.55	0.55	0.55	0.55	0.55	Present	Present
Ala	2.97	2.96	2.95	2.67	2.66	2.65		
Arg	3.52	3.51	3.51	3.17	3.16	3.15	Present	
ASP	4.89	4.89	4.88	4.43	4.42	4.42		
Glu	8.98	8.89	8.81	7.88	7.78	7.69		
Gly	2.45	2.44	2.44	2.20	2.20	2.19		
His	1.39	1.38	1.36	1.24	1.22	1.21	Present	
Ile	2.22	2.21	2.19	1.98	1.97	1.96		
Leu	4.46	4.45	4.43	4.00	3.99	3.97		
Lys	3.89	3.88	3.88	3.82	3.82	3.82	Present	
Met	1.34	1.33	1.32	1.30	1.30	1.30		
Phe	2.39	2.38	2.36	2.13	2.12	2.10		
Ser	2.36	2.35	2.34	2.11	2.10	2.09		
Tau	0.50	0.50	0.50	0.50	0.50	0.50		
Thr	2.28	2.27	2.26	2.14	2.14	2.14		
Tyr	1.76	1.76	1.75	1.58	1.57	1.55		
Val	2.82	2.82	2.81	2.54	2.53	2.52		
Pro	2.46	2.36	2.25	2.04	1.93	1.82		

*Also contains: Poultry meal, fish meal, soybean meal, feather meal, poultry oil, water, mold inhibitor, astaxanthin, vitamin E, ethoxyquin, vitamin C, hydrogenated vegetable oil, virocam, HT mix, panaferd-AX, luctarom, potato starch, canthaxanthin, monoammonium, propylene glycol, yeast autolysate dehydrated, zinc proteinate, guar gum, dadex defend, nasmix, nucleotide, sodium butyrate.

**Also contains: Fish meal, mold inhibitor, vitamin C, vitamin E, ethoxyquin

Table 5. The dietary formulation and composition for the commercial diets used in both Trial 1 and 2.

	Commercial Diet	
Ingredients	**BioTrout 2.0 mm**	**Skretting Europa 2.0 mm**
Crude Protein (Minimum %)	47	55
Crude Fat (Minimum %)	24	15
Crude Fiber (Maximum %)	1.8	2
Phosphorus (Mininmum %)	1	2

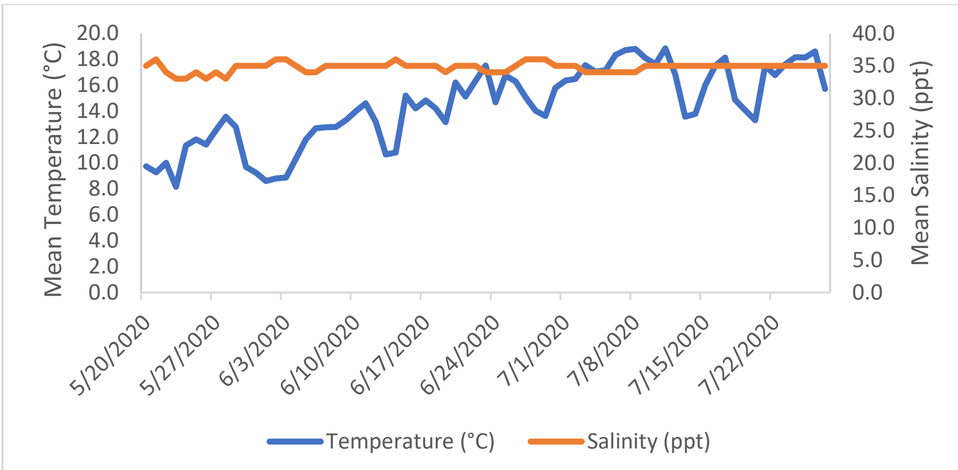

Figure 5. Mean daily temperature and salinity during Trial 1.

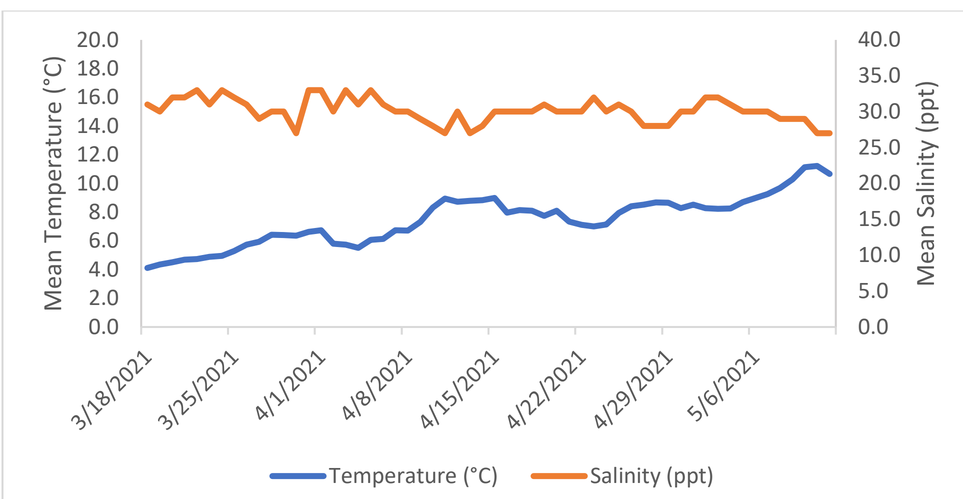

Figure 6. Mean daily temperature and salinity during Trial 2.

Results

Trial 1

Fish survival was not impacted by diet in Trial 1, with only two mortalities reported. One fish died in the 55/20 treatment on 7/9/20 and another fish diet in the 47/24 (BioTrout) treatment on 7/27/20.

Lumpfish grew from an average of 8g to 40-79g over the course of the study (Figure 7). Overall mean fish growth rates varied from 0.47 ± 0.18 g/day to 0.96 ± 0.36 g/day depending on the diet treatment (Table 6, Figure 7). Fish fed the 55/20 and 55/15 diets had significantly faster growth than fish fed the 50/15, 55/15 (Europa), and 47/24 (BioTrout) diets (one-way ANOVA, $p < 0.0001$, Table 6, Figure 7). Overall mean percent growth varied from 394.00 ± 30.03 % to 781.45 ± 36.35 % and was affected by diet. Fish in the 55/15 treatment had significantly higher overall mean percent growth (781.45 ± 36.35 %) than fish in in the 47/24 (BioTrout) and 55/15 (Europa) treatments (394.00 ± 30.03 % and 632.86 ± 33.09 %, respectively, one-way ANOVA, $p < 0.0001$) but did not have greater growth than fish in the remaining diet treatments (Figure 8). Overall mean weight gain ranged from 32.57 ± 2.23 g to 67.30 ± 3.14 g and was also affected by diet. Fish fed the 55/20 and 55/15 experimental diets had significantly higher weight gain than fish fed the 50/15, 47/24 (BioTrout), and 55/15 (Europa) diets (one-way ANOVA, $p < 0.0001$, Table 6, Figure 9). Fish fed the BioTrout diet had significantly lower weight gain than fish in any other diet treatment (one-way ANOVA, $p < 0.0001$, Table 6, Figure 9). The BioTrout treatment was the only plant-based protein, salmonid diet, therefore, growth was also analyzed excluding this treatment. When the 47/24 (BioTrout) diet, a plant protein-based diet, was removed from analyses, fish in the 55/15 treatment had significantly higher weight gain than fish in the 50/15 and 55/15 (Europa) treatments (one-way ANOVA, $p = 0.0039$, Table 6, Figure 10). Mean specific growth rates were also impacted by diet and varied from 0.023 ± 0.001 g/day to 0.031 ± 0.0001 g/day. Fish fed the 55/15 diet had a significantly higher specific growth rate than fish fed the 47/24 (BioTrout) and 55/15 (Europa) diets, however, no differences existed between the experimental treatments (one-way ANOVA, $p < 0.0001$, Table 6, Figure 11). Feed conversion ratios ranged from 1.10 ± 0.01 to 1.54 ± 0.09 with the commercial salmon having higher FCR compared to all the other diets (one-way ANOVA, $p < 0.0001$, Figure 12). Generally, fish fed a high protein lower lipid diet, a commercial marine finfish diet, had good growth results compared to fish fed a salmon diet (lower protein and higher lipid). Proximate composition of the whole fish did not vary with dietary treatment except for lipid which was increased in the fish fed the commercial salmon diet (Table 7).

Diet did not affect the occurrence of fish aggression ($X^2(7, N = 448) = 0.39, p = 0.9997$). Mean percentage of fin nipping occurrence ranged from 1.00 ± 0.91 % in the 55/15 treatment to 14.22 ± 7.79 % in the 55/15 (Europa) treatment (Table 6, Figure 13). Because final mean severity of fish nipping was low and only ranged from 0.01 ± 0.01 to 0.19 ± 0.12 (Table 6) and only 2.9 % of fish had fin nipping damage above a level 1 (out of 5), the severity of fin nipping data were not analyzed. Thirteen fish out of 448 fish sampled showed fin damage above a level 1: one fish in the 55/10 treatment, one fish in the 50/20 treatment, two fish in the 55/20 treatment, one fish in the 50/10 treatment, one fish in the 47/24 (BioTrout) treatment, and four fish in the 55/15 (Europa) treatment.

Trial 2

The five diets evaluated in Trial 2 did not affect survival, growth, or aggression in juvenile Lumpfish (Table 8), Fish survival was 100% throughout the eight-week period.
Overall mean fish growth rate for each diet treatment varied from 0.64 ± 0.36 g/day to 0.72 ± 0.38 g/day and was not influenced by diet (one-way ANOVA, $p = 0.7863$, Table 8, Figure 14). Diet also did not impact overall mean percent growth, which ranged from 424.41 ± 34.07 % to 486.98 ± 88.70 % (one-way ANOVA, $p = 0.6909$, Figure 15). Overall mean weight gain was also unaffected by diet, varying from 35.96 ± 3.46 g to 40.14 ± 6.99 g (one-way ANOVA, $p = 0.7863$, Figure 16). Mean specific growth rates varied from 0.025 ± 0.0001 g/day to 0.027 ± 0.0002 g/day and were not affected by diet either (one-way ANOVA, $p = 0.6772$, Figure 17). Feed conversion ratios were not influenced by diet as well and varied from 0.75 ± 0.07 to 0.82 ± 0.07 (one-way ANOVA, $p = 0.7178$, Figure 18).

Diet did not impact fish aggression in Trial 2. Only two out of the 120 fish sampled showed evidence of fin damage. Therefore, fish aggression analyses were not performed.

Trial 1

Table 6. The results of the different testing parameters measured for Trial 1. Different superscript letters denote statistical differences between treatments in each column.

Diet Treatment (protein/ lipid)	**Final Overall Percent Growth (± one standard deviation, %)**	**Mean Growth Rate (± one standard deviation, g/day)**	**Mean Weight Gain (± one standard deviation, g)**	**Mean Specific Growth Rate (± one standard deviation, g/day)**	**Mean Feed Conversion Ratio (± one standard deviation)**	**Final Mean Occurrence of Fin Nipping (± one standard deviation, %)**	**Final Mean Severity of Fin Nips (± one standard deviation)**	**Final Percent Survival (%)**	**Final Mean Fish Weight (± one standard deviation, g)**
50/15	690.86 (±61.44)^{ab}	0.82 (± 0.35)^{b}	57.05 (± 3.62)^{b}	0.030 (±0.001)^{ab}	1.14 (± 0.06)^{b}	1.67 (± 1.18)	0.02 (± 0.01)	100.00	65.33 (± 3.47)
55/10	718.55 (± 30.55)^{ab}	0.86 (± 0.42)^{ab}	60.06 (± 1.83)^{ab}	0.030 (± 0.001)^{ab}	1.16 (± 0.02)^{b}	3.67 (± 1.83)	0.05 (± 0.02)	100.00	68.42 (± 1.73)
50/20	684.77 (± 62.59)^{ab}	0.85 (± 0.32)^{ab}	59.18 (± 5.14)^{ab}	0.029 (± 0.001)^{ab}	1.16 (± 0.07)^{b}	5.33 (± 1.39)	0.08 (± 0.02)	100.00	67.82 (± 5.13)
55/20	752.26 (± 36.20)^{ab}	0.95 (± 0.36)^{a}	66.34 (± 1.84)^{a}	0.031 (± 0.001)^{ab}	1.14 (± 0.07)^{b}	6.33 (± 4.31)	0.09 (± 0.06)	97.78	75.18 (± 2.06)
55/15	781.45 (± 36.35)^{a}	0.96 (± 0.36)^{a}	67.30 (± 3.14)^{a}	0.031 (± 0.001)^{a}	1.10 (± 0.01)^{b}	1.00 (± 0.91)	0.01 (± 0.01)	100.00	75.92 (± 3.28)
50/10	705.51 (± 77.48)^{ab}	0.87 (± 0.33)^{ab}	60.69 (± 6.88)^{ab}	0.030 (± 0.001)^{ab}	1.13 (± 0.06)^{b}	4.33 (± 3.65)	0.06 (± 0.04)	100.00	69.30 (± 7.06)
47/24 (BioTrout)	394.00 (± 30.03)^{c}	0.47 (± 0.18)^{c}	32.57 (± 2.23)^{c}	0.023 (± 0.001)^{c}	1.54 (± 0.09)^{a}	8.00 (± 1.99)	0.13 (± 0.04)	97.78	40.84 (± 2.17)
55/15 (Europa)	632.86 (± 33.09)^{b}	0.78 (± 0.27)^{b}	54.90 (± 3.09)^{b}	0.028 (± 0.001)^{b}	1.23 (± 0.06)^{b}	14.22 (± 7.79)	0.19 (± 0.12)	100.00	63.58 (± 3.19)

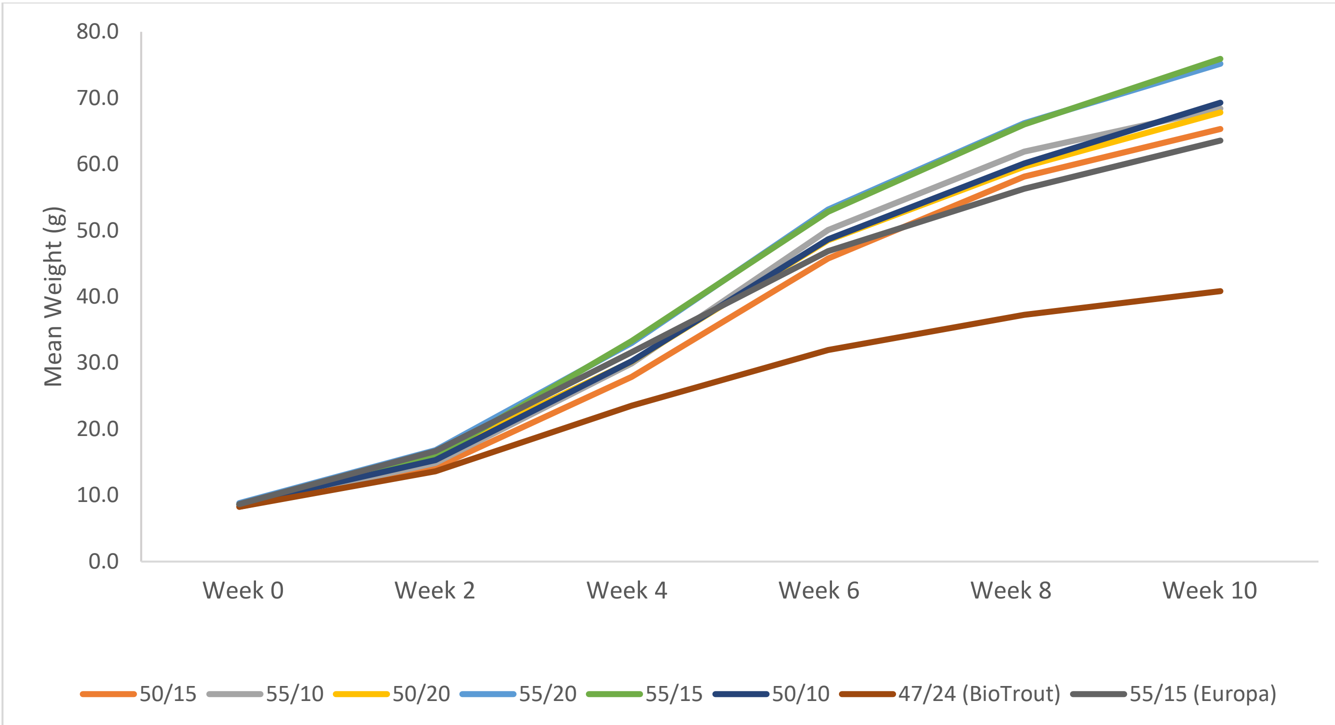

Figure 7. Mean weights of the juvenile Lumpfish over time in each diet treatment in Trial 1, including the BioTrout treatment.

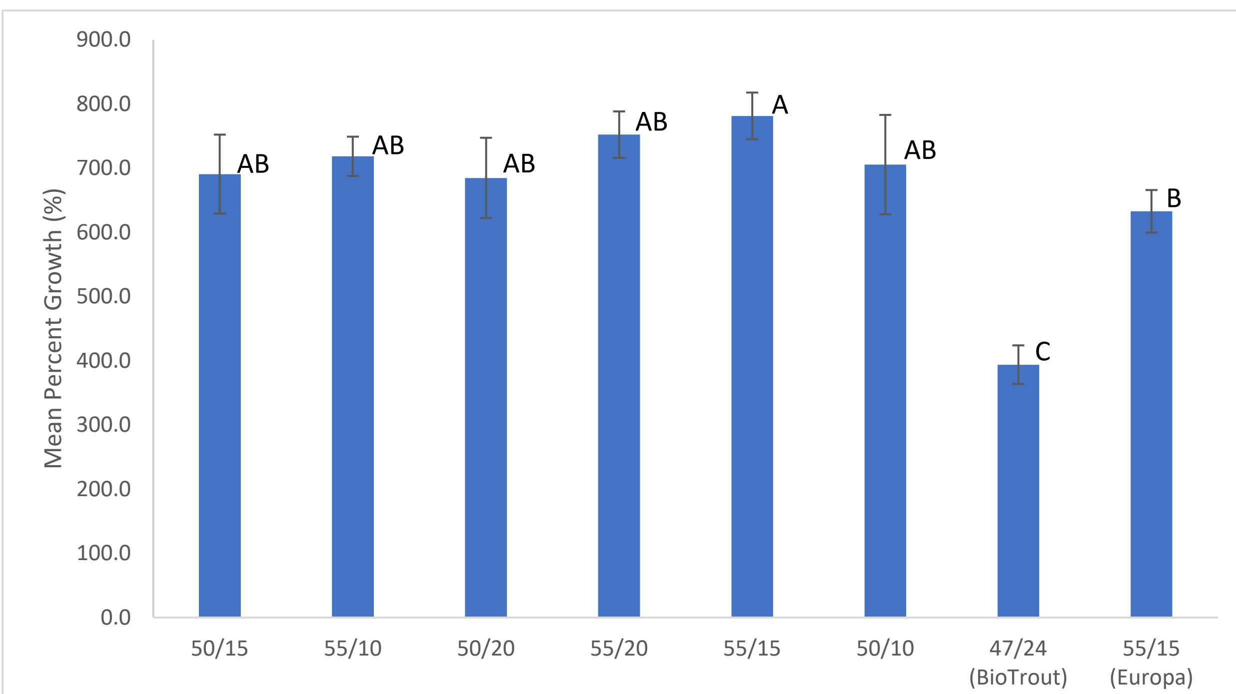

Figure 8. Overall mean percent growth (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 1, including the BioTrout diet. Differing letters denote significant differences between treatments.

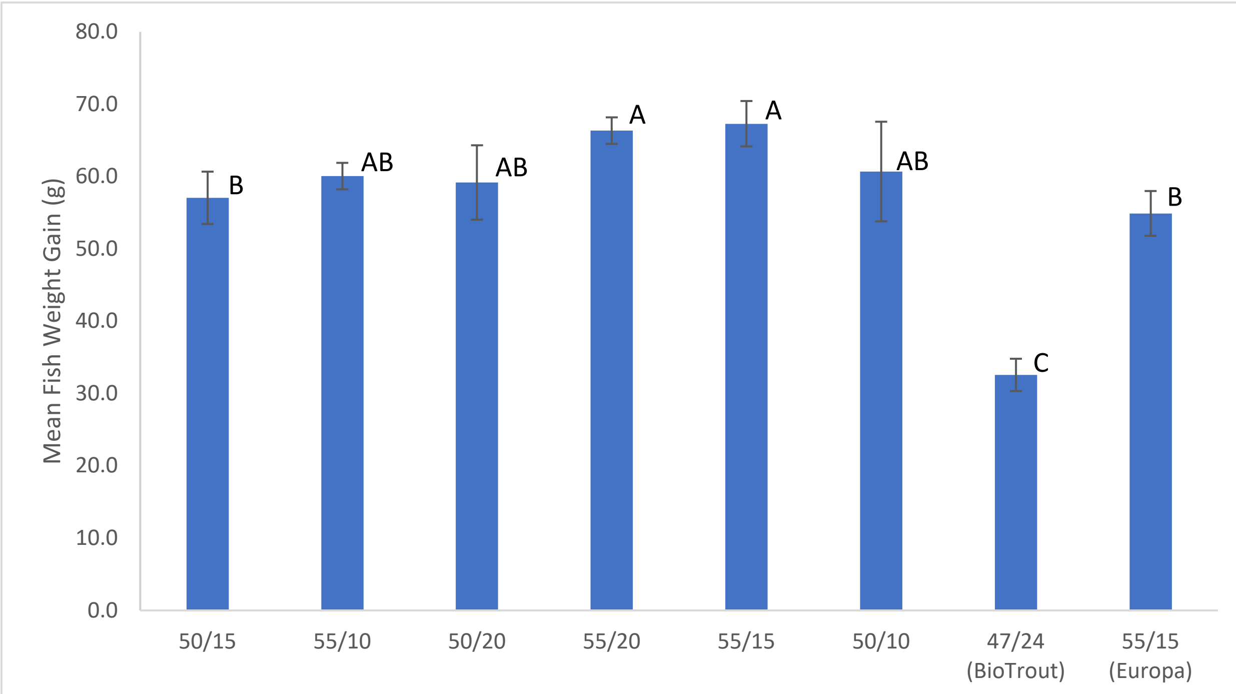

Figure 9. Overall mean weight gain (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 1, including the BioTrout diet. Differing letters denote significant differences between treatments.

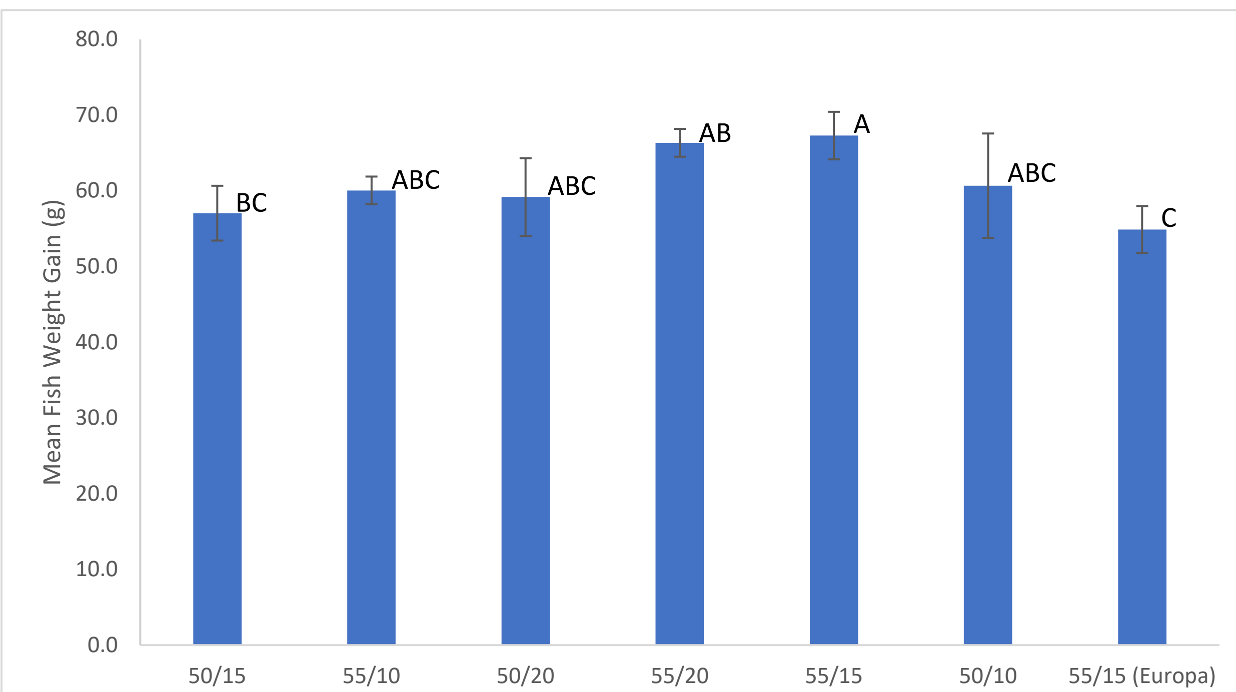

Figure 10. Overall mean weight gain (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 1, excluding the BioTrout diet. Differing letters denote significant differences between treatments.

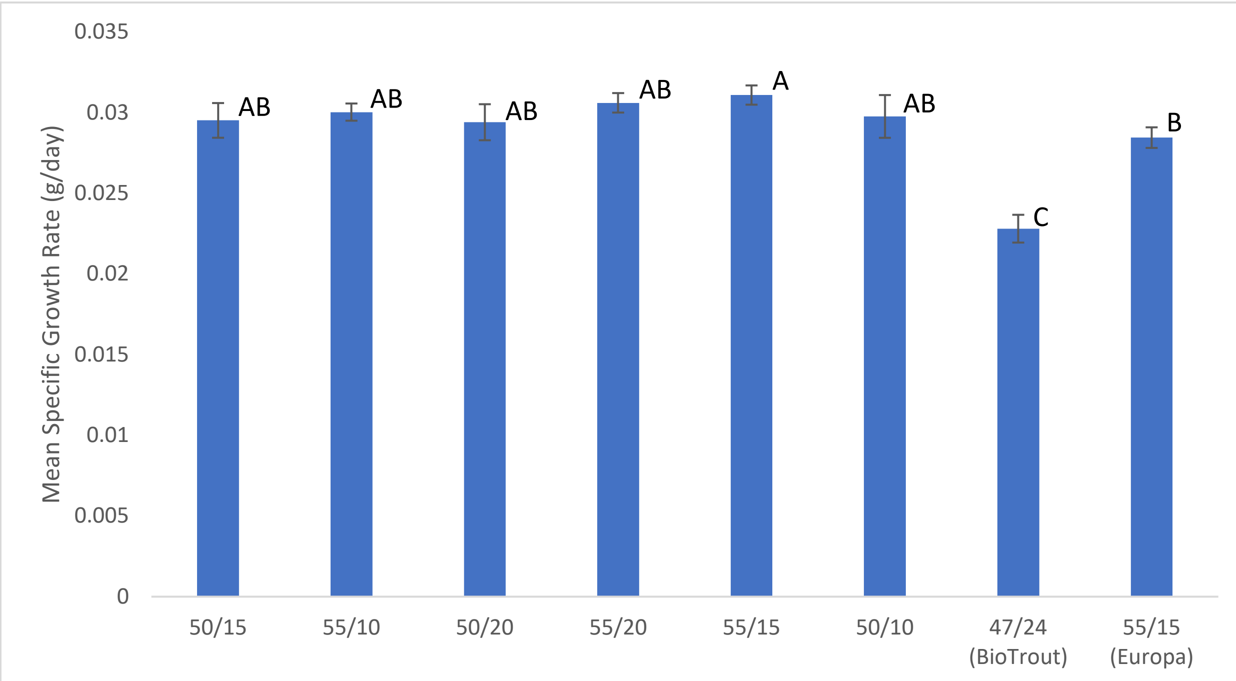

Figure 11. Overall mean specific growth rate (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 1, including the BioTrout diet. Differing letters denote significant differences between treatments.

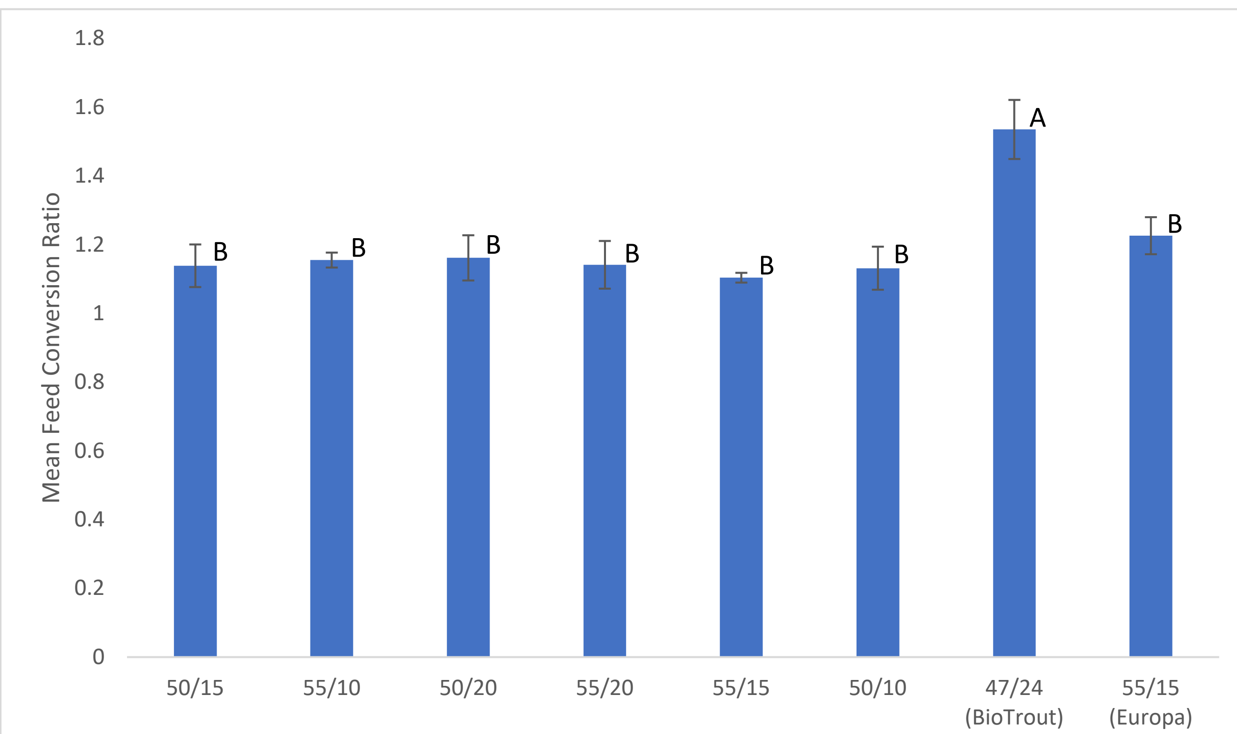

Figure 12. Overall mean feed conversion ratio (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 1, including the BioTrout diet. Differing letters denote significant differences between treatments.

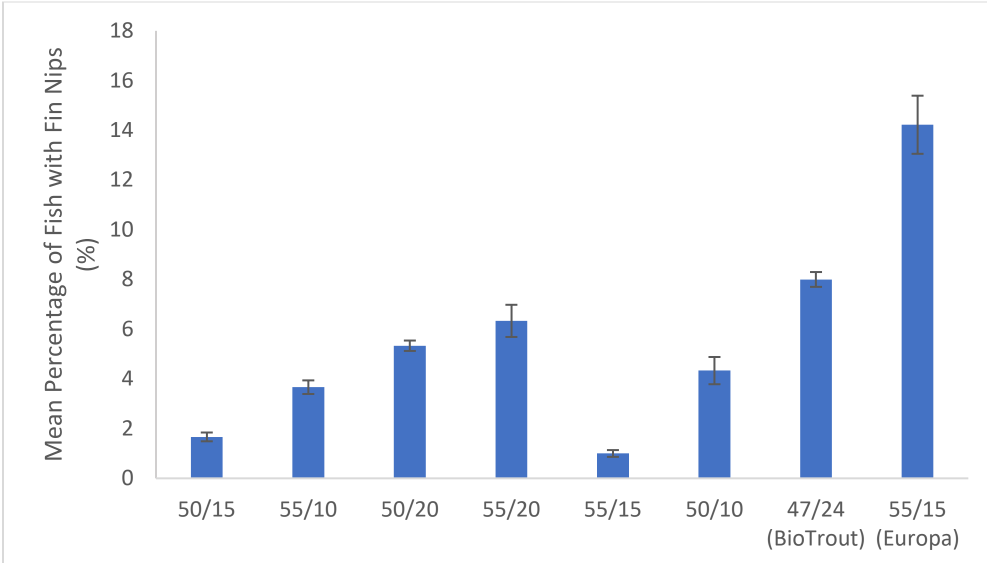

Figure 13. Mean occurrence (± one standard deviation) of juvenile Lumpfish aggression in each diet treatment in Trial 1, including the BioTrout treatment.

Table 7. UNH lumpfish diet Trial 1 (proximate analysis of the whole fish).

Diet	% Protein	% Lipid	% Moisture
1 (50/15)	60.3	18.5	87.5
2 (55/10)	60.8	18.1	87.2
3 (50/20)	60.6	18.8	87.5
4 (55/20)	60.3	19.1	87.5
5 (55/15)	59.3	18.3	87.5
6 (50/10)	60.8	18.0	87.3
7 (BioTrout)	60.6	21.1	86.4
8 (Europa)	60.7	18.4	87.7

Trial 2

Table 8. The results of the different testing parameters measured for Trial 2.

Diet Treatment (protein/ lipid)	Final Overall Percent Growth (± one standard deviation, %)	Mean Growth Rate (± one standard deviation, g/day)	Mean Weight Gain (± one standard deviation, g)	Mean Specific Growth Rate (± one standard deviation, g/day)	Mean Feed Conversion Ratio (± one standard deviation)	Final Percent Survival (%)	Final Mean Fish Weight (± one standard deviation, g)
55/10	424.41 (± 34.07)	0.64 (± 0.36)	35.96 (± 3.46)	0.025 (± 0.001)	0.80 (± 0.05)	100.00	44.43 (± 3.59)
50/20	468.60 (± 38.66)	0.71 (± 0.43)	39.98 (± 4.08)	0.026 (± 0.001)	0.75 (± 0.07)	100.00	48.50 (± 4.26)
55/20	486.98 (± 88.70)	0.72 (± 0.38)	40.14 (± 6.99)	0.027 (± 0.002)	0.77 (± 0.10)	100.00	48.38 (± 6.93)
55/15	467.52 (± 20.44)	0.70 (± 0.39)	39.27 (± 1.29)	0.026 (± 0.001)	0.76 (± 0.02)	100.00	47.67 (± 1.32)
55/15 (Europa)	463.72 (± 54.54)	0.69 (± 0.30)	38.60 (± 4.68)	0.026 (± 0.001)	0.82 (± 0.07)	100.00	46.93 (± 4.76)

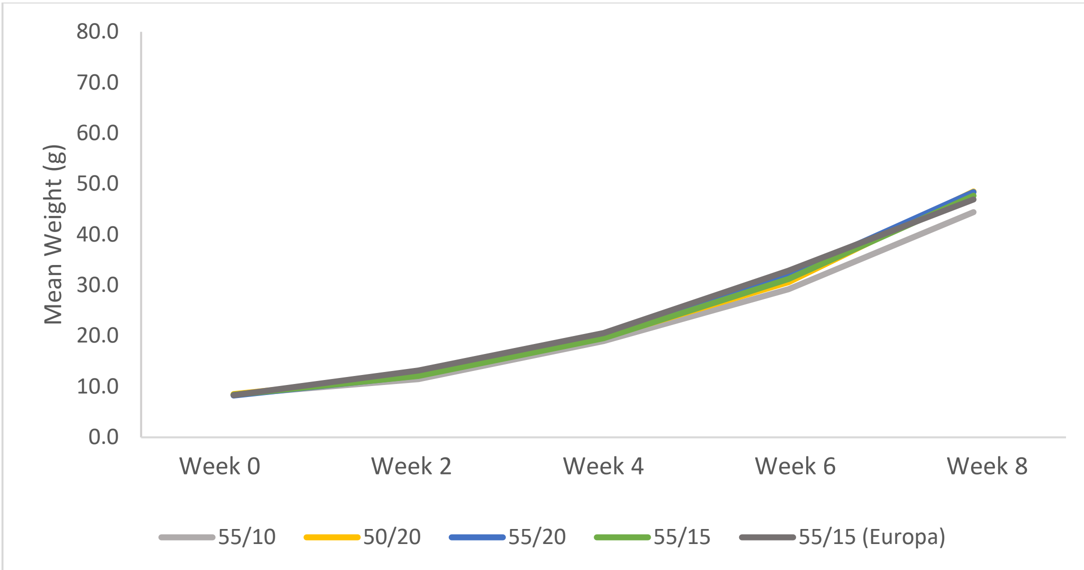

Figure 14. Mean weights of juvenile Lumpfish over time in each diet treatment in Trial 2.

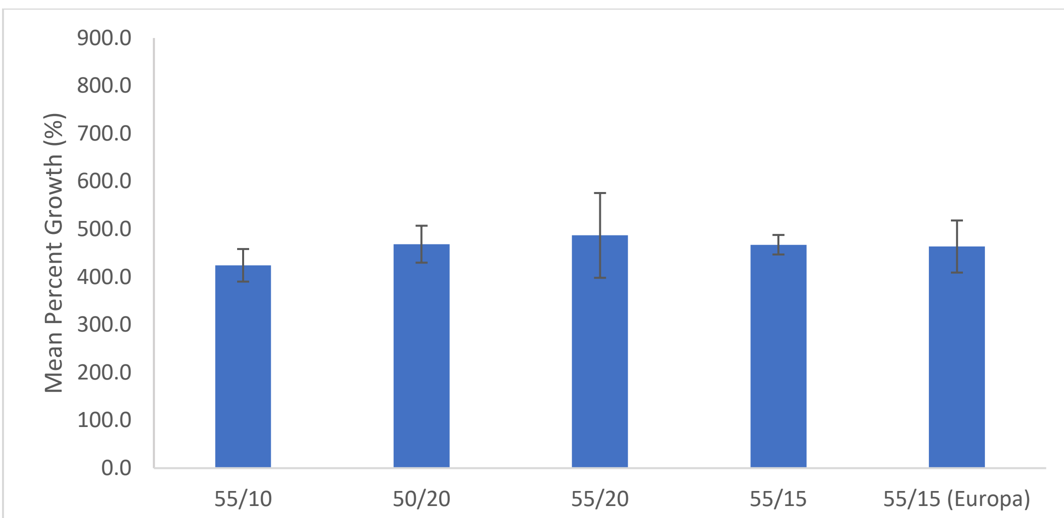

Figure 15. Overall mean percent growth (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 2 at week 8.

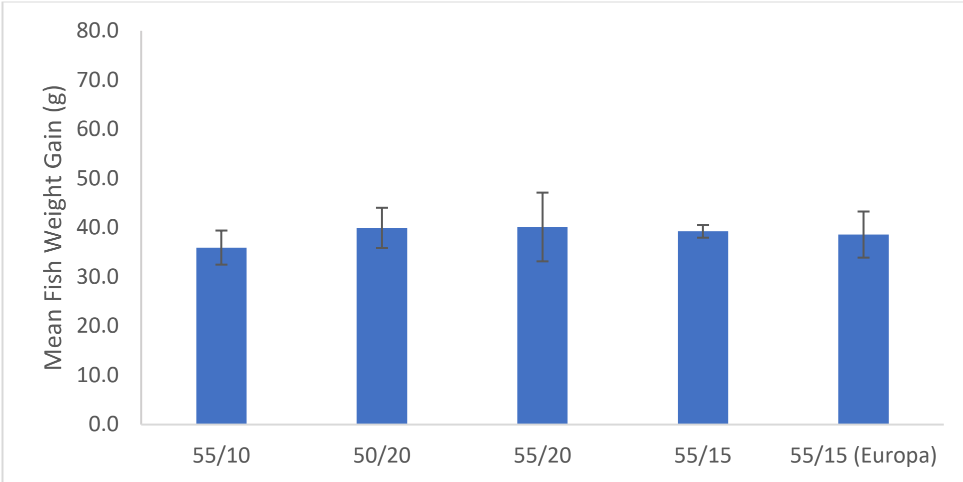

Figure 16. Overall mean weight gain (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 2.

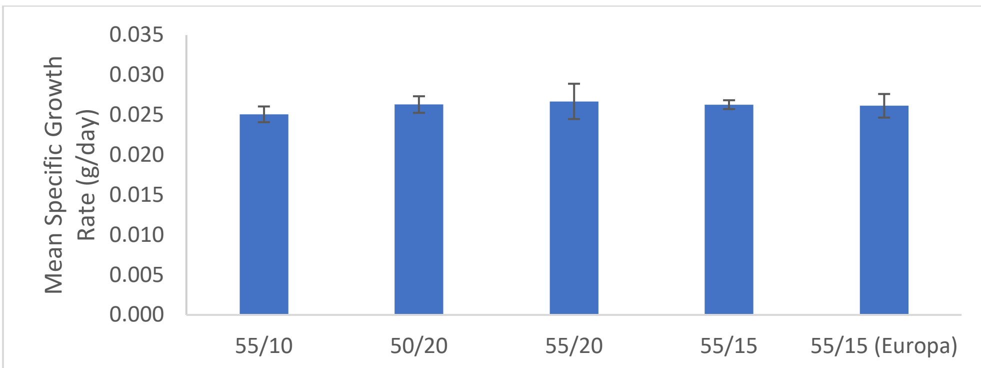

Figure 17. Overall mean specific growth rate (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 2.

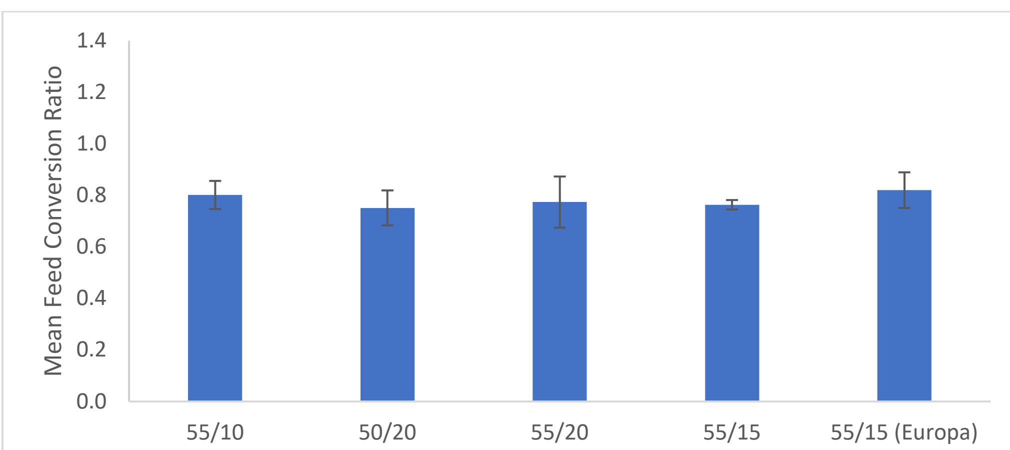

Figure 18. Overall mean feed conversion ratio (± one standard deviation) of juvenile Lumpfish in each diet treatment in Trial 2.

NCWMAC trial: Lumpfish from UNH were transported to the USDA to conduct the juvenile diet trial once the USDA new lumpfish facilities were established. The diet trial was conducted for 8 weeks from June 12 to Aug. 7, 2020. The study was conducted in 24 16-L tanks initially stocked with 20 fish weighing 15 g (±2.9 g). Diets were randomly assigned to tanks in triplicate and fish were fed twice daily to satiation. Fish were individually weighed, and the weight of feed fed per tank was recorded biweekly. At week 6, five fish were removed from each tank after weighing to reduce tank densities to below 40 kg/m^3. A subsample of fish at week 0 and at the end, week 8, were euthanized and frozen for proximate composition analysis.

Lumpfish grew from an average of 15g to 41-62g over the course of the study (Figure 19). Fish fed the commercial salmon diet (BioTrout, 45% protein/24% lipid) grew the least with 277% increase and fish fed the commercial diet (Europa) or the 55/10 (% protein/% lipid) diet grew the most with only the salmon diet being significantly different from the other treatments (Figure 19). These results are similar to what was observed at UNH. Generally, fish fed a high protein lower lipid diet, a commercial marine finfish diet, had good growth results compared to fish fed a salmon diet (lower protein and higher lipid). Proximate composition of the whole fish did not vary with dietary treatment except for lipid which was increased in the fish fed the commercial salmon diet (Table 9).

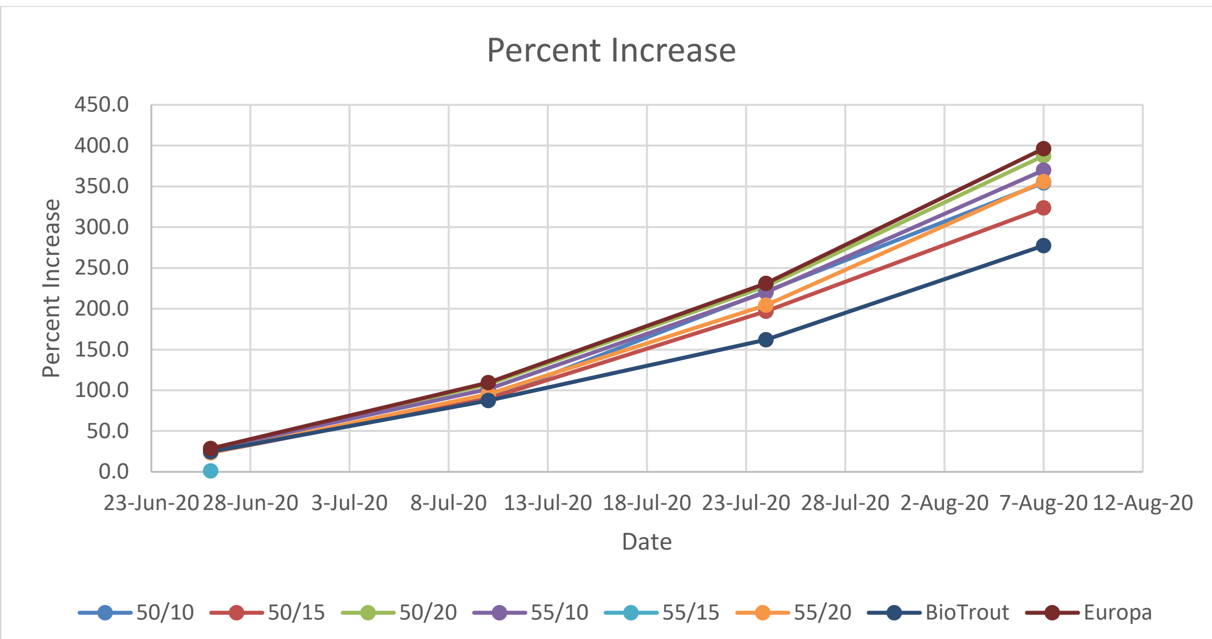

Figure 19. NCWMAC lumpfish diet trial (percent increase).

Table 9. NCWMAC lumpfish diet trial (proximate analysis of the whole fish).

Diet #	% Protein	% Lipid	% Moisture
1 (Commercial salmon feed)	60.6	19.7	86.0
2 (50/10)	60.3	18.3	87.8
3 (50/15)	60.4	18.4	87.5
4 (50/20)	60.6	18.5	87.2
5 (55/10)	60.8	18.6	87.4
6 (55/15)	60.8	18.7	87.6
7 (Commercial marine feed)	60.7	18.5	87.5
8 (55/20)	60.7	18.4	87.3

Objective 3: Conveying research findings to stakeholders by developing lumpfish husbandry guides and standard operating procedures and holding workshops.

Covid-19 disrupted most of our in-person outreach plans to present at meetings, and host workshops or sessions to help promote knowledge and the use of lumpfish.

At the beginning of Year 2 (Jan. 22, 2020), we held a hybrid workshop at the UNH Judd Gregg Marine Complex, New Castle, NH which included a total of 12 personnel from UNH, UME CCAR, USDA NCWMAC, Cooke Aquaculture USA, and Cooke Aquaculture LLC (Canada). We discussed: 1) progress to date on the lumpfish aquaculture research activities, 2) industry constraints and how research programs could help, and 3) future cleanerfish needs in the salmonid industries and strategies to allow expansion of using cleanerfish in the US. Tours were provided of the lumpfish production at the UNH Coastal Marine Lab. We also helped to organize and present in a cleanerfish session at Aquaculture America 2020 in Feb. 2020.

However, from March 2020 - Dec. 2021, in-person outreach was not possible. In particular, the pandemic postponed the industry workshops initially planned for the end of the project which we still hope to have beyond this research award. Additionally, the Northeast Aquaculture Conference & Exposition (NACE) was postponed from Jan. 2021 until Jan. 2022, and then postponed again until April 2022. We had intended to organize a cleanerfish session at the original Jan. 2021 meeting but that has been put on hold until we know all PIs of this project as well as some our stakeholders will have permission to travel. Another cleanerfish session was planned for Aquaculture America 2021 but cancelled since UNH and the federal government still prohibited travel at the time of the conference planning plus the US-Canada border remained closed and many speakers would not have been able to attend. We hope to plan a cleanerfish session at a future Aquaculture America meeting when travel is more predictable. In addition, farm tours at the UNH steelhead trout farm were not permitted during Years 2 and 3 due to restricted access during Covid-19.

Despite the stringent restrictions on in-person meetings, we managed to conduct quite a bit of outreach and we broadened our outreach mission to focus on enhancing public understanding and increasing awareness of the impact sea lice has on salmonid farms and that using lumpfish as "biological delousers" is a sustainable way to help control sea lice. This was done through guest lectures in undergraduate students courses; presentations, videos, and displays at a non-profit, public, marine science education center; connecting with the public at UNH open houses, both to recruit students and to inform the general public; Zooming with girl scouts from across the country who want to know what it's like to be a marine biologist; and working closely with media outlets (local and state newspapers, state agricultural radio shows, online seafood newsletters, and international aquaculture trade publications) to reach broader audiences (the articles published about this research are included in Part I of the this final report).

Lastly, we wrote a hatchery guide for lumpfish culture based on our research findings, experience, and knowledge of others'. This manual is awaiting final approval from internal USDA review, then will be posted on the NRAC website and shared directly with Cooke Aquaculture personnel.

PROJECT COMPLETION REPORT

SIGNATURE PAGE

PROJECT CODE: 18-03 **SUBCONTRACT NO:**

PROJECT TITLE:

Improving Hatchery Techniques of Lumpfish (*Cyclopterus lumpus*) for Use as a Cleaner Fish to Control Sea Lice in Atlantic Salmon and Steelhead Trout Net Pens

PREPARED BY:

Elizabeth Fairchild

____ 1/31/2022

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Project Coordinator of Subawardee Date