NRAC FINAL PROGRESS 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
Reporting Period	7/1/2021-12/31/2021
Author (Project Coordinator)	Elizabeth Fairchild
Key Words	lumpfish, nutrition, larviculture, strip spawning, egg incubation, sea lice mitigation, cleaner fish, salmonids
Funding Level	Total funds allocated for this project to date. *Year One: FY 2020, $ 100,000* *Year Two: FY 2021, $ 100,000*
Participants: Names, Institutions and Contact Info	*Dr. Elizabeth A. Fairchild: Project Coordinator & lead PI Associate Research Professor, Department of Biological Sciences, University of New Hampshire, Durham, NH 03824; ph: 603-862-4475; fax: 603-862-3784; elizabeth.fairchild@unh.edu Dr. Brian Peterson: co-PI Center Director, USDA ARS National Cold Water Marine Aquaculture Center 25 Salmon Farm Rd., Franklin, ME 04634 (207) 422-2713; Fax: N/A; brian.peterson@ars.usda.edu *Dr. Michael Pietrak: co-PI Research Associate, USDA ARS National Cold Water Marine Aquaculture Center, 25 Salmon Farm Rd, Franklin, ME 04364; Ph: (207) 812-0605; Fax: N/A; michael.pietrak@ars.usda.edu *Dr. Gary Burr: co-PI Research Physiologist, USDA ARS National Cold Water Marine Aquaculture Center, Franklin, USDA ARS National Cold Water Marine Aquaculture Center, 25 Salmon Farm Rd, Franklin, ME 04364; Ph: (207) 422-2716; Fax: N/A; gary.burr@ars.usda.edu *Dr. Michael Chambers: co-PI and lead outreach coordinator Aquaculture Specialist, NH Sea Grant & Cooperative Extension, University of New Hampshire, Durham, NH 03824; ph: 603-862-3394; michael.chambers@unh.edu Dr. Keng Pee Ang: Cooperating non-funded industry partner Vice President of Research, Cooke Aquaculture, 40 Wellington Row, St. John, New Brunswick, Canada E2L 3H3; ph: 506-456-6600; keng.pee.ang@cookeaqua.com

	Note: Dr. Keng Pee Ang has retired from Cooke Aquaculture during this reporting period and was replaced on this project by his successor, Andrew Swanson. In addition, we added another funded NH outreach member to the team, Arron Jones. Dr. Andrew Swanson: Cooperating non-funded industry partner Vice President of Research, Cooke Aquaculture, 40 Wellington Row, St. John, New Brunswick, Canada E2L 3H3; ph: 506-456-6600; andrew.swanson@cookeaqua.com *Arron Jones: Outreach coordinator Aquaculture Program Manager, NH Sea Grant, University of New Hampshire, Durham, NH 03824; arron.jones@unh.edu
Project Objectives	**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 briefly how the project will benefit the aquaculture industry – 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.

Project Progress	Summarize concisely for each objective the progress toward accomplishment to date. This has an 8,000 character limit. **The following was accomplished during this reporting period:** **Objective 1:** Optimizing lumpfish hatchery techniques for early life history stages. *Ho 1: Declumping the naturally, sticky lumpfish eggs will increase survival and hatching.* No new updates on this objective during this reporting period. **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). No further updates occurred during this reporting period. *Ho 4: Varying protein and fat levels will affect the growth and survival of juvenile lumpfish.* During this reporting period we completed proximate composition and data analysis. <u>UNH Juvenile Diet Trial:</u> Lumpfish grew from an average of 8g to 40-79g over the course of the study. 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. 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, $p < 0.0001$). 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. 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, $p < 0.0001$). Fish fed the BioTrout diet had significantly lower weight gain than fish in any other diet treatment (one-way ANOVA, $p < 0.0001$). 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, $p = 0.0039$). 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, $p < 0.0001$). 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, $p < 0.0001$). 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 1).

Table 1. 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

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. Because final mean severity of fish nipping was low and only ranged from 0.01 ± 0.01 to 0.19 ± 0.12 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.

NCWMAC Juvenile Fish Trial:
Lumpfish grew from an average of 15g to 41-62g over the course of the study. 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 1). 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 2).

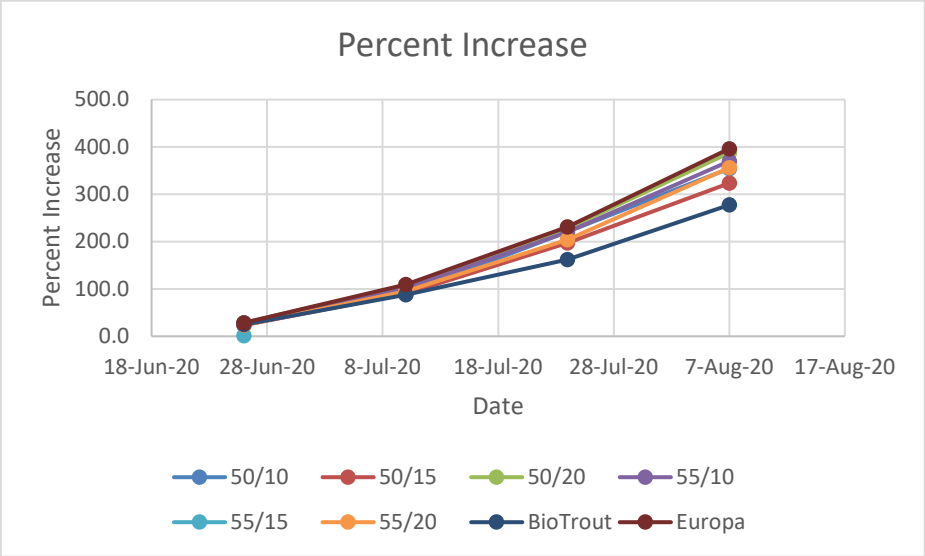

Figure 1. NCWMAC lumpfish diet trial (percent increase).

Table 2. 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. The pandemic continued to disrupt outreach plans to present our findings at meetings like NACE which has been postponed yet again. While beyond the time frame of this grant, we hope to share our findings at future scientific meetings such as NACE when it convenes again (April 2022) and at WAS North America (Aug 2022). We completed a hatchery guide for lumpfish culture and are awaiting final approval from internal USDA review before the guide can be posted on the NRAC website. Once this occurs, we will also share it with Cooke Aquaculture.
Accomplishments:	
Outreach Overview	Describe in general how your results have been extended to the intended users. OR, if they haven't yet, explain when & how this will occur. Many of our final outreach activities we planned to do in person were not possible due to the pandemic including a final workshop with salmonid farmers and tours of the UNH IMTA farm and at the NCWMAC to showcase this research project. We continued to bring attention to lumpfish culture and their use as cleanerfish during this reporting period using the following platforms: The project is featured on the UNH School of Marine Science and Ocean Engineering's website at https://marine.unh.edu/resource/lumpfish-research. We informed the public and aquaculture stakeholders (scientists, industry) about the importance of this research through news articles including: UNH Media: • Featured in the UNH Research Snapshot Series in an article written by Lori Gula "Research Snapshot: Raising Lumpfish." This was picked up by the NOAA Headquarters Aquaculture Literacy Initiative and included in their weekly email. https://www.unh.edu/unhtoday/2021/07/research-snapshot-raising-lumpfish (July 26, 2021). • Featured in an article in Thrive: "Advancing aquaculture." Fall 2021, pp. 9-11. We wrote a lumpfish hatchery manual which will be shared with the public via the NRAC website and directly with Cooke Aquaculture once the manual has final approval from USDA.

	Two UNH Master's students defended their theses that focused on cleanerfish. Their seminars were held on Zoom and advertised to the cleanerfish community. Attendees included members of the US Lumpfish Consortium and commercial cleanerfish stakeholders. Further copies of their theses were requested by commercial aquaculture stakeholders including Cooke Aquaculture's cleanerfish group and Bio-Oregon (feed manufacturer).
Targeted Audiences	Provide information on the **target audience** for efforts designed to **cause a change in knowledge, actions, or conditions**. Our target audiences have included students (K-12, undergraduate, and graduate) to educate them about sustainable aquaculture and developments in domestic seafood production. By working with university students, we are training the next crop of marine scientists. We also have targeted other scientists and academics along with aquaculture industry members to work together towards solving limitations in domestic salmonid farming. We have targeted the international cleanerfish community so that we receive relevant guidance from those who already have initiated cleanerfish hatcheries and use in salmonid farms in their home countries. We also continue to communicate with state regulators about this research and need to utilize cleanerfish in finfish aquaculture farms within state waters so that a permitting pathway can be created to allow salmonid farmers to stock lumpfish in their farms.
Outputs:	Outputs are tangible, measurable products (website, events, workshops, products [AV, curricula, models, software, technology, methods, websites, patents, etc.], trainees, etc.). Do NOT include publications as they're listed separately. The funding and research of this project has spurred the creation of the US Lumpfish Consortium by the PIs. This informal group consists of researchers from UNH, USDA, UMaine, Cooke Aquaculture (both US and Canadian groups), Kennebec River Biosciences, and Memorial University of Newfoundland. The group is open to any persons or groups interested in promoting research on the culture and use of lumpfish in US aquaculture. To date the consortium members have submitted research proposals to Sea Grant (2 full proposals, 1 pre-proposal which will be submitted as a full proposal in Feb. 2022), NOAA Saltonstall-Kennedy Program (1), NRAC (1 new proposal in 2020; 3 pre-proposals submitted in 2021, 2 of which were invited for full proposal submission and both have been recommended by the NRAC BOD for funding), Maine Technology Institute (1), USDA NIFA NH AES (2), and USDA AFRI (1). These efforts have resulted in <u>four proposals being funded</u>: 1) "Sustainable US Cleanerfish Production: Developing a Lumpfish Broodstock Program," funded by NOAA S-K Program to UNH for $296,337; 1/1/2021-12/31/2022; lead PI Elizabeth Fairchild.

	2) "Developing strategies to minimize sea lice infestation in cage cultured steelhead trout and advancing lumpfish aquaculture," funded by USDA NIFA NH AES to UNH for approx. $70,000; 9/1/2019-8/31/2021; lead PI Elizabeth Fairchild. NH AES funded UNH Master's student Michael Doherty with a GRA to focus on cleanerfish use in steelhead trout cages. 3) "Advancing lumpfish aquaculture and their use as biological delousers in salmonid ocean farms," funded by USDA NIFA NH AES to UNH for approx. $75,000; 9/1/2021-8/31/2024; lead PI Elizabeth Fairchild. NH AES funded UNH Master's student Shelby Perry with a GRA to focus on lumpfish aggression in the hatchery. 4) "Team LuMP: Lumpfish mapping project," funded by NH Sea Grant to UNH for $55,180; 1/1/22-12/31/22; lead PI Elizabeth Fairchild. Further, <u>two proposals are recommended for funding</u> by the NRAC BOD: 1) "Improving lumpfish grow-out production: Optimizing feed strategies," recommended for funding by NRAC to UNH for $199,826; 4/1/22-3/31/24; lead PI Elizabeth Fairchild. 2) "Improving lumpfish breeding and spawning," recommended for funding by NRAC to USDA ARS NCWMAC for $200,000; 1/1/23-12/31/25; lead PI Mike Pietrak.
Outcomes/Impacts:	Describe how findings, results, techniques, or other products that were developed or extended from the project generated or contributed to an outcome/impact. **Outcomes/impacts are defined as changes in Knowledge, Action, or Condition.** • 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 developed to support industry and public research efforts. • The first commercial US lumpfish hatchery is under construction and expected to be operational in spring 2022.
Impacts Summary	Provide short statements (2-3 sentences) about each of the following: (pre-established fields for Researchers to complete short statement answers) 1. **Relevance:** Issue – what was the problem? The US has the potential to increase domestic aquaculture finfish production by utilizing cleanerfish to combat sea lice infestation in salmonid sea cages.

	2. **Response:** What was done? We have raised (and are still raising) lumpfish. We have worked with commercial fishermen to try to establish a wild-caught lumpfish broodstock. We have examined experimental diets to learn more about the nutritional needs of young lumpfish. We have experimented with multiple husbandry systems and techniques between facilities to gain experience. We have formed collaborations and organized talks about cleanerfish to educate the public and our stakeholders about cleanerfish use and why it could be beneficial if used in the US. We have mentored and equipped undergraduate and graduate students with essential aquaculture skills so that they are knowledgeable scientists and employable in aquaculture sectors. We have written a lumpfish hatchery guide based on our knowledge and culture experiences to help others rear lumpfish successfully. 3. **Results:** How did your work make a difference **(change in knowledge, actions, or conditions)** to the target audiences? Lumpfish production in US research facilities has increased and there is a greater understanding in the US about cleanerfish use in fish farms. We have expanded the interest by researchers, across a range of disciplines, in lumpfish culture and increased the number of proposals being submitted and secured. The first commercial US lumpfish hatchery is expected to be operational in spring 2022. 4. **Recap:** One- sentence summary There is industry interest in using lumpfish as a cleanerfish in US salmonid farms and we have shown that small-scale hatchery production of lumpfish is feasible in university facilities.
Publications	Follow the format to list publications in the following categories: • Presentations: o Oral 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. o Posters • Peer-reviewed:

	○ Print (journal, etc.) ○ Digital (websites, videos, etc.) • Non-Peer-reviewed: Spada, N. N. 2021. Improving larval and juvenile lumpfish, *Cyclopterus lumpus*, aquaculture: nutrition and growing conditions. Master's Thesis, Dept. 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. ○ ○ Extension factsheets ○ Popular articles
Students/Participants:	Shelly Lancaster: • University of New Hampshire; B.S. in Natural Resources • New undergraduate student • No capstone or thesis related to this project • Anticipated date of graduation: 5/2022 Nathaniel Spada: • University of New Hampshire; M.S. in Biological Sciences: Marine Biology • MS student • Improving larval and juvenile lumpfish, *Cyclopterus lumpus*, aquaculture: nutrition and growing conditions • Graduation date: 1/2022 • No link to thesis yet Mary Kate Munley: • University of New Hampshire; B.S. in Marine, Estuarine & Freshwater Biology • Undergraduate student • No capstone or thesis related to this project • Graduation date: 5/2021 Andrew Shapiro: • University of New Hampshire; B.S. in Marine, Estuarine & Freshwater Biology • Undergraduate student • No capstone or thesis related to this project

	• Graduation date: 5/2021 Alexander Gross: • University of New Hampshire; B.S. in Marine, Estuarine & Freshwater Biology • Undergraduate student • No capstone or thesis related to this project • Graduation date: 5/2021 Michael Doherty: • University of New Hampshire; M.S. in Biological Sciences: Marine Biology • MS student • Interactions and behaviors of lumpfish, *Cyclopterus lumpus,* and steelhead trout, *Oncorhynchus mykiss*, and sea lice prevalence in experimental open water aquaculture cages • Graduation date: 9/2021 • https://scholars.unh.edu/thesis/1504 Alex Lora • University of Maine; BS Marine Science with Aquaculture concentration • Continuing student • No capstone or thesis related to this project • Anticipated Date of Graduation: Spring 2022 Marissa Burr • Delaware Valley University; BS Environmental Biology • Continuing student • No capstone or thesis related to this project • Anticipated Date of Graduation: Spring 2023 Bayley Bryant • University of Maine; BS Marine Science • Intern (recent graduate) • Graduation date: Spring 2020
Partnerships	List any partners that you worked with on your project. Provide the following information for each Partner: • Dr. Gibson Gaylord (USFWS Fish Nutritionist): reviewed experimental diet formulations and manufactured the diets for the juvenile feeding study • Jason Frost (USDA ARS Biological Science Technician): reviewed experimental diet formulations and manufactured diets for the larval

feeding study

- Danny Boyce (Memorial University of Newfoundland, Aquaculture Facilities Manager): provided advice and guidance on the culture of lumpfish and provided lumpfish eggs in 2019 and 2020
- Geoffrey McBriarty (Cooke Aquaculture Lumpfish Production Coordinator): provided advice and guidance on lumpfish care and husbandry
- Frank Lank (Cooke Aquaculture USA): assisted with efforts to collect wild lumpfish from Atlantic salmon net pens in Maine
- Mike Brown (Cooke Aquaculture USA): assisted with efforts to collect wild lumpfish from Atlantic salmon net pens in Maine
- Steve Eddy, Melissa Malmstedt, Ben Reed (University of Maine Center for Cooperative Aquaculture Research Director and Technicians): collected wild young of the year lumpfish in Maine for grow-out to sexual maturity (i.e., future broodstock) and also growing out UNH reared lumpfish
- Greg Lambert (Cooke Aquaculture USA): provided advice and guidance on timing of lumpfish hatchery operations and logistics to coincide with needs at the Atlantic salmon farms in Maine

Partner	**Specific Type** Type	**Level** Level	**Nature of Partnership**