Parasites of Commercially Important Marine Fish Species and their Potential as Population Biological Tags

Executive Summary

Ensuring the effective and sustainable management of Scotland's marine environment is crucial to the long term prosperity of this natural resource for future generations. With this in mind a MASTS funded two day workshop was held in Aberdeen on the 5th and 6th of September 2017 titled "Parasites of Commercially Important Marine Fish Species and their Potential as Population Biological Tags" at the University of Aberdeen (day 1) and Marine Scotland (day 2).

The organisers (Dr Campbell Pert, Marine Scotland Science, Dr Ken MacKenzie from the University of Aberdeen and Dr Cecile Reed from University of Cape Town, South Africa) developed the workshop for students and early career scientists so that those attending the workshop would develop fish parasitology skills and techniques as well as allowing them the opportunity to present their research in the field of marine fisheries parasitology to an International audience of parasite experts in the less intimidating environment of a workshop rather than a large conference. Furthermore, the knowledge gained from the meeting not only contributed to the attendees' understanding of a range of fish parasitology issues but also allowed delegates to disseminate information to their peers and network with Internationally renowned scientists and wider MASTS community in the field of fish parasitology.

Introduction

Scotland is among the largest sea fishing nations in Europe, with Scottish fishing vessels landing around two-thirds of the total fish caught in the United Kingdom. In 2014, Scottish based vessels landed a total of 481 thousand tonnes of sea fish and shellfish, with a value of £514 million. The number of active fishing vessels based in Scotland was 2,030 and directly employed 4,796 fishermen at the end of 2014.

Healthy fish populations provide long-term fishing opportunities for the sea fishing industry and natural food for consumers, as well as being of great importance to the marine ecosystem around the Scottish coastal zone.

As such it was decided to hold a two day workshop, generously funded by MASTS, titled "Parasites of Commercially Important Marine Fish Species & Their Potential as Population Biological Tags?" in Aberdeen on the 5th and 6th of September 2017. The workshop comprised one day of a laboratory based practical session led by Dr Ken MacKenzie (University of Aberdeen) and Dr Cecile Reed (University of Cape Town, South Africa) held at Aberdeen University, with a second day of presentations (See abstract book) held at the Marine Scotland Marine Laboratory with plenary presentations by Dr MacKenzie and Dr Reed.

Dr MacKenzie's work on parasites in fisheries is widely respected. In recent years (2010 onwards) he has been instrumental in establishing a successful research programme on parasites infecting commercial fish species in South Africa together

with scientists from the Department of Agriculture, Forestry and Fisheries (DAFF) (Dr Carl van der Lingen & Larvika Singh) and the University of Cape Town (Dr Cecile Reed). This approach had never been explored in South Africa, where most marine parasitological research had previously focused on taxonomic descriptions. In particular, no multidisciplinary applied parasitological research had been conducted in South Africa until then. Since the start of the project on parasites of commercially important fish species in South Africa in 2010, 13 species of wild-caught fisheries species (*Engraulis encrasicolis*, *Sardinops sagax*, *Trachurus capensis*, *T. trecae*, *Merluccius capensis*, *M. paradoxus*, *Thyrsites atun*, *Lophius vomerinus*, *Genypterus capensis*, *Brama brama*, *Etrumeus wongratinae*, *E. whiteheadi*, *Callorhinchus capensis*, *Squalus acutipinnis*) have been surveyed for their parasite communities with the aims of applying this data to management in the form of stock assessment studies. Furthermore, three of these species (Kingklip – *G. capensis*, monkfish – *L. vomerinus* and sardine – *S. sagax*) are currently under study in a 'multi-method approach' for stock assessment. This methodology involves the use of several stock assessment methodologies, including parasites as biological tags, to determine if any, or all, of these methods provide similar, or improved, results compared to when they are used individually.

Dr Reed has 13 years' experience working in the field of Parasitology. Her PhD (obtained in 2003) research focussed on the taxonomy of fish myxosporeans in both freshwater and marine fishes in South Africa and Botswana. She is currently employed as a senior lecturer in the Department of Biological Sciences, University of Cape Town, where her research group focuses on studying the parasites of commercially important marine fishes in South Africa. Her research team comprises two MSc and four PhD students as well as fisheries biologists from DAFF in South Africa and Dr. MacKenzie from the University of Aberdeen. The multidisciplinary collaboration that currently supports applied parasitological research at UCT was initiated by Dr Reed who realised the need to work with a wide range of expertise to ensure the success of the program.

The organisers felt that forging collaboration with South Africa will be of tremendous benefit to MASTS and the University of Cape Town students and early career scientists where attendees could look at the opportunities to share information, network with international colleagues and investigate future collaborative projects designed to benefit and enrich both countries culturally and scientifically.

Therefore the aims and outcomes of the workshop were –

1) Explain the theory of using parasites as biological tags for important commercial species and describe the potential and benefits to fisheries management worldwide.

2) Invite workshop attendees to a day's practical parasitology work under the guidance of the organisers to develop skills in fish dissection as well as isolating a range of parasites from gadoids caught in the Scottish coastal zone and identifying these, where possible, to species level.

3) Deliver a presentation on the practical application of the technique of utilising parasites as biological tags in South Africa and lessons that could be learned for adopting such an approach in Scotland.

4) Provide a forum for students and early career scientists to present their work in the fish parasitology field to their scientific peers and also share/learn practical techniques with attendees.

Day 1 – Dissection Workshop

On the 5th of September 19 attendees gathered in the foyer of the University of Aberdeen, Zoology building to attend the practical fish dissection and parasite identification session led by Dr Ken MacKenzie assisted by Dr Cecile Reed, Dr Campbell Pert and Irfan Nunkoo (Figure 1). A short introduction on the range of parasites that attendees could potentially find was delivered by Ken MacKenzie before attendees (Figures 2 – 5) were invited to dissect a range of marine fish species (Atlantic cod, haddock, whiting and saithe), isolate any parasitic organisms and attempt to identify them using light microscopes.

Figure 1: The "Parasites of Commercially Important Marine Fish Species and their Potential as Population Biological Tags" workshop organisers from left: Dr Ken MacKenzie, Irfan Nunkoo, Dr Cecile Reed and Dr Campbell Pert.

Figure 2: Ken MacKenzie demonstrating parasite isolation from a haddock to one of the workshop attendees.

Figure 3: Campbell Pert discussing the range of parasitic fauna that can be found in gadoids from the Scottish coastal zone.

Figure 4: Ken MacKenzie demonstrating a structured fish dissection and parasite isolation techniques on a large Atlantic cod to workshop attendees.

Figure 5: The lab facilities at Aberdeen University and assistance from University technician staff were invaluable to the success of the day.

One Day Dissection Workshop

During the practical one day workshop held at Aberdeen University workshop attendees learned how to carry out a methodical fish dissection to determine the parasitic fauna and loading that gadoids from the Scottish coastal zone may have. Additionally, having isolated the parasite from the fish, attendees were then shown how to mount the parasites onto slides and use a light microscope to magnify specific areas of the parasites to allow identification to species level.

The attendees isolated a number of different parasite species, including the parasitic nematodes *Anisakis simplex*, *Hysterothylacium aduncum* and *Spinitectus oviflagellis,* the parasitic copepods *Lernaeocera branchialis* and *Caligus elongatus*, the digenean *Derogenes varicus,* the cestode *Abothrium gadi* and the acanthocephalan *Corynosoma* sp.

Figure 6: Workshop attendees found not only parasites during the fish dissections but also what some of the species had been feeding on – this cod had been found to have eaten 7 adult herring!

Figure 6: Encysted *Anisakis simplex* infesting the liver of a whiting during the MASTS funded parasitology workshop practical held at Aberdeen University.

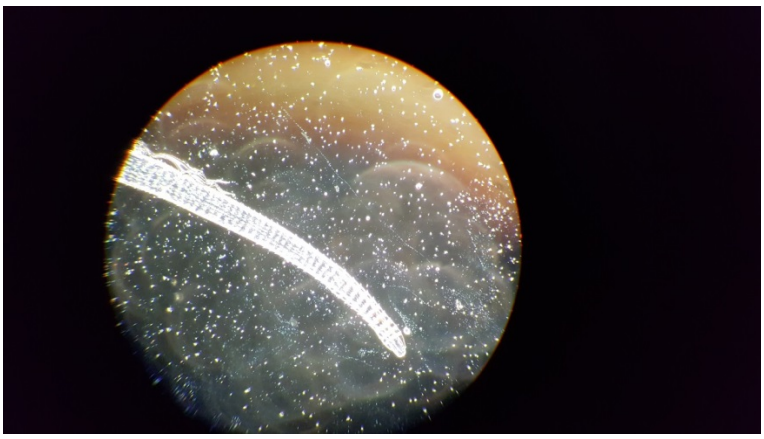

Figure 7: The parasitic nematode *Spinitectus* oviflagellis found in an Atlantic cod (*Gadus morhua*) during fish dissections.

Figure 8: The parasitic copepod *Lernaeocera branchialis* was found in the gills of a number of fish during the workshop.

One Day Parasitology Seminar

The aim of the one day seminar was to allow students and early career scientists the opportunity to present their research in the field of marine fisheries parasitology to an International audience of parasite experts in the less intimidating environment of a workshop rather than a large conference. The full program is below and all the abstracts supplied by presenters are in the workshop program book supplied along with this report. The day's programme was started with a welcome introductory message from Marine Scotland Science's Head of Science Professor Colin Moffat before a very interesting plenary from Dr Ken MacKenzie titled "Parasites as Biological Tags in Population Studies of Marine Fish: General Principles and Examples" giving all present an overview of this field of work. There were a further six presentations covering all aspects of parasite infesting commercially important marine fish from sea lice on Atlantic salmon through parasites of King scallops to parasites of biological tags both in Scotland and South Africa.

Day 2 (6th September 2017) Presentations at Marine Scotland Marine Laboratory

Attendees to report to the reception at the Marine Scotland Marine Laboratory and sign in from 09:00 before being escorted to the lecture theatre where talks will commence at 09:30 with a plenary presentation by invited speaker Dr Ken MacKenzie (University of Aberdeen).

Time	Speaker	Presentation title	Abstract #
09:30	Dr Campbell Pert	Introduction of the day's programme, talks and "housekeeping" rules for attendees.	
09:40	Dr Ken MacKenzie	"Parasites as Biological Tags in Population Studies of Marine Fish: General Principles and Examples."	**1**
10:20	Roman Susdorf	"Sea Lice Effect on Wild Atlantic Salmon Fecundity."	**4**
10:40	Campbell Pert	"Developing a method to investigate infestation pressure from sea lice on migratory salmonids utilising towed and static sentinel cages."	**5**
11:00		Coffee Break	
11:30	Dr Neil Campbell	"Application of parasites as biological tags to current problems in Scottish fisheries science."	**2**
12:10	Peter Gibson	"Survey of king scallops (*Pecten maximus*) for the presence of Apicomplexan parasite in the Scotland"	**6**
12:30	Alex Kent	"Red Vent Syndrome in Atlantic salmon (*Salmo salar* L.): Do dietary inputs and parasitic component communities of salmon populations reflect different migratory routes?"	**7**
12:50	Dr Campbell Pert	Opportunity for any questions and discussion on the mornings' talks	
13:00		Lunch in Lecture theatre	
14:00	Dr Cecile Reed	"Parasites as biological tags in South African marine research"	**3**
14:40	Irfan Nunkoo	"Parasites as indicators of population structure of snoek (*Thyrsites atun*) in the Benguela ecosystem"	**8**
15:00		Coffee Break	
15:20	Dr Campbell Pert	Discussion on day's presentations, possible future work and day's summary.	
16:00	Dr Cecile Reed	Thanks and Closing	

Feedback From Workshop Attendees

Attendees were invited to provide constructive feedback on the workshop, good or bad, to allow us to make improvements for similar events in the future as the demand and uptake for the current event was excellent.

The full, unedited, responses received by the organisers are included below -

"Dear Campbell
Thank you again for organizing this workshop. It was very interesting and good fun. The talks were very interesting and it was great to have talks about various aspects concerning marine prasitology and from different universities. During the first day it might have been helpful to have done a demonstration dissection that showed how a parasitology assessment is routintly done. But overall it was a great experience."
Nina Lobeto

"I thoroughly enjoyed both days and thought it was amazing that this was free and available to students. The practical was very interesting, even with the lack of parasites! My only suggestion would be more instruction or information on what we were looking for. I had very little experience in parasite work and found it slightly difficult to know exactly what I was looking for. Maybe might have been better having Ken dissect a fish first?

All of the talks given on the second day were great and opened me up to a topic in my marine biology degree.

Overall, I took this course as I had little parasitology experience and wanted to learn more. I have come away with more awareness and appreciation for the topic and am glad I had the chance to take this course.

Thank you for an informative (and well organised) two days!"
Megan Riddell

"I wanted to thank you for giving me the opportunity to attend this workshop. It was very enjoyable and fascinating. The dissections, all the talks were very interesting, especially Cecile's talk."
Cecilia Pugna

"Sorry for the delay in sending this email. This is just about the recent marine parasitology workshop.
I had a great time! It was fascinating seeing the various kinds of parasites within the fish, and I learned a lot with you and the other organisers' expertise, both about the parasites and a bit about dissection techniques. The talks were also interesting. It was a shame we couldn't see the marine Scotland labs, but I suppose it was a security issue? It might have been good to look at some non-fish and discuss how their parasites differ from the fish.
Also, thanks for discussing postgrad options with me. I hope you don't mind me sending an email if I have any further questions about that."
Cat Venters

Summary

Overall, the organisers and (from feedback) attendees felt the workshop met all the aims and outcomes the organisers had envisaged when making the grant application to MASTS. By holding this workshop it enabled my colleagues and I to share our fish parasitology experience and techniques as well as allow students and early career scientists to present their research in the field of marine fisheries parasitology. Many of the attendees took full advantage of the event to discuss their own future plans and investigate potential areas of study, particularly with my South African colleagues, which we hope, will lead to future collaborations and new entrants into the field of parasitology.

Parasites of Commercially Important Marine Fish Species and their Potential as Population Biological Tags

Aberdeen, Scotland 5th & 6th September 2017

Programme and Abstracts

A workshop hosted by:

Marine Alliance for Science and Technology for Scotland

UNIVERSITY OF ABERDEEN

marinescotland

The Scottish Government
Riaghaltas na h-Alba

Table of Contents

Foreword

Scotland is among the largest sea fishing nations in Europe, with Scottish fishing vessels landing around two-thirds of the total fish caught in the United Kingdom. In 2014, Scottish based vessels landed a total of 481 thousand tonnes of sea fish and shellfish, with a value of £514 million. The number of active fishing vessels based in Scotland was 2,030 and directly employed 4,796 fishermen at the end of 2014.

Healthy fish populations provide long-term fishing opportunities for the sea fishing industry and natural food for consumers, as well as being of great importance to the marine ecosystem around the Scottish coastal zone.

Ensuring the effective and sustainable management of Scotland's marine environment is crucial to the long term prosperity of this natural resource for future generations. Therefore, we are looking forward to hosting this two day workshop in Aberdeen on "Parasites of Commercially Important Marine Fish Species and their Potential as Population Biological Tags" at the University of Aberdeen (day 1) and Marine Scotland (day 2) on the 5th and 6th of September 2017.

The workshop will comprise a day of laboratory-based practical dissections at the Department of Zoology, University of Aberdeen followed by a day of presentations by invited speakers, including Dr Ken MacKenzie from the University of Aberdeen, Dr Cecile Reed from University of Cape Town, South Africa, and Dr Neil Campbell (Marine Scotland) as well as a number of postgraduate students who will have the opportunity to share their research with their peers.

It is envisaged that attending this workshop will help attendees to develop fish parasitology skills and techniques and will allow students and early career scientists the opportunity to present their research in the field of marine fisheries parasitology to an International audience of parasite experts in the less intimidating environment of a workshop rather than a large conference. Furthermore, the knowledge gained from the meeting will not only contribute to the attendees' understanding of a range of fish parasitology issues but will also allow delegates to disseminate information to their peers and the wider MASTS community.

Dr Campbell Pert
Parasitologist
Marine Scotland Science

Invited speakers

Dr Ken Mackenzie and Dr Cecile Reed

Dr MacKenzie's work on parasites in fisheries is widely respected. In recent years (2010 onwards) he has been instrumental in establishing a successful research programme on parasites infesting commercial fish species in South Africa together with scientists from the Department of Agriculture, Forestry and Fisheries (DAFF) (Dr Carl van der Lingen & Larvika Singh) and the University of Cape Town (Dr Cecile Reed). The method had never been explored in South Africa, where most marine parasitological research focused on taxonomic descriptions. In particular, no multidisciplinary applied parasitological research had been conducted in South Africa until then. Since the start of the project on parasites of commercially important fish species in South Africa in 2010, 13 species of wild-caught fisheries species (*Engraulis encrasicolis*, *Sardinops sagax*, *Trachurus capensis*, *T. trecae*, *Merluccius capensis*, *M. paradoxus*, *Thyrsites atun*, *Lophius vomerinus*, *Genypterus capensis*, *Brama brama*, *Etrumeus wongratinae*, *E. whiteheadi*, *Callorhinchus capensis*, *Squalus acutipinnis*) have been surveyed for their parasite communities with the aims of applying these data to management in the form of stock assessment studies. Furthermore, three of these species (Kingklip – *G. capensis*, monkfish – *L. vomerinus* and sardine – *S. sagax*) are currently under study in a 'multi-method approach' for stock assessment. This methodology involves the use of several stock assessment methodologies, including parasites as biological tags to determine if any, or all, of these methods provide similar, or improved, results compared to when they are used individually.

Dr Reed has 13 years experience working in the field of Parasitology. Her PhD (obtained in 2003) research focussed on the taxonomy of fish myxosporeans in both freshwater and marine fishes in South Africa and Botswana. She is currently employed as a senior lecturer in the Department of Biological Sciences, University of Cape Town, where her research group focuses on studying the parasites of commercially important marine fishes in South Africa. Her research team comprises three MSc and four PhD students as well as fisheries biologists from DAFF in South Africa and Dr. MacKenzie from the University of Aberdeen. The multidisciplinary collaboration that currently supports applied parasitological research at UCT was initiated by Dr Reed who realised the need to work with a wide range of expertise to ensure the success of the program.

Dr Neil Campbell

Dr Neil Campbell started his career at the University of Aberdeen in 2000, working on projects investigating the use of parasites as biological tags to investigate the stock structure of horse mackerel and herring around the coasts of the UK and Europe. The work he did under these projects contributed to his PhD thesis. Since then, Dr Campbell has had a varied career, working on Nephrops stock assessment, fishes behaviour, deep sea biodiversity and the ecosystem approach to fishery management. After a five year stint in Canada in a science advisory role, Dr Campbell returned to Marine Scotland and now leads the Fisheries Analysis and Assessment Group, attempting to align scientific research with the needs of policymakers and stakeholders.

PROGRAMME

Day 1 (Tuesday 5th September 2017)
Parasitology dissection to commence at 09.30 with attendees to gather in the foyer of the University of Aberdeen, Zoology building by 09:15 before going to lab ZB03.

A short introduction will be delivered by Ken MacKenzie before attendees will be invited to dissect a range of marine fish species and isolate parasitic organisms and attempt to identify them using microscopes.

At 12.00 there will be a break for lunch (not provided, but The Hub close to the Zoology Department provides a wide choice of food). The workshop will resume at 13.00 with an anticipated finish time of 16:00.

Time	Activity
09:15	Gather in the foyer of the University of Aberdeen, Zoology before going to lab ZB03
09:30	Introduction to parasitological dissection: Dr Ken MacKenzie
09:45	Dissections commence
12:00	**Lunch**
13:00	Dissections resume
16:00	Closing

Day 2 (6th September 2017) Presentations at Marine Scotland Marine Laboratory

Attendees to report to the reception at the Marine Scotland Marine Laboratory and sign in from 09:00 before being escorted to the lecture theatre where talks will commence at 09:30 with a plenary presentation by invited speaker Dr Ken MacKenzie (University of Aberdeen).

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16:00	Dr Cecile Reed	Thanks and Closing	

Abstracts

1) PARASITES AS BIOLOGICAL TAGS IN POPULATION STUDIES OF MARINE FISH: GENERAL PRINCIPLES AND EXAMPLES

Ken MacKenzie

University of Aberdeen, Zoology Building, Tillydrone Avenue, Aberdeen AB24 2TZ, UK

The first paper describing the use of a parasite as a biological tag for a marine fish species was published in 1939. Since then the method has been used with increasing frequency in population studies of commercially important marine fish, facilitated by advances in our knowledge of the biology and ecology of marine parasites. The basic principle underlying the use of parasites in this way is that fish can become infected with a parasite only when they are within the endemic area of that parasite. The endemic area is that geographic area within which conditions are suitable for the transmission of the parasite, including biotic factors such as the presence of other hosts necessary for the completion of the parasite's life cycle, and abiotic factors such as temperature and salinity. If infected fish are found outside the endemic area, we can infer that those fish had been within that area at some time in their past history. Fish thus carry a "parasitological fingerprint" that enables us to trace their past movements. Knowledge of the maximum life span of a tag parasite in a particular host species allows us to estimate the period of time since the infected fish left the parasite's endemic area. Guidelines to the selection of appropriate tag parasites are given, together with guidance on data analysis and interpretation of results.

Parasite tags can be used effectively in population studies of small delicate fish species, such as small clupeoids, and for deep water fish, for which artificial tags can be used with difficulty or not at all. They are also valuable for identifying subpopulations distinguished by behavioural differences, but between which there is a considerable amount of gene flow. In such cases, genetic studies alone may prove inconclusive.

The talk is illustrated by examples of successful biological tag studies using a variety of parasites.

2) APPLICATION OF PARASITES AS BIOLOGICAL TAGS TO CURRENT PROBLEMS IN SCOTTISH FISHERIES SCIENCE

Neil Campbell

Marine Scotland Science, 375 Victoria Road, Aberdeen.

We live in times of unusually rapid climatic, economic and political change. To support the management process in such a volatile environment, decision makers need access to timely and accurate scientific advice. Studies of the use of parasites as biological tags provides a tool to study stock identity and trace the migratory patterns of marine fish stocks of interest to Scotland, with the potential to inform discussions on resource allocation, protective measures and mitigation strategies. This presentation discusses a number of key challenges facing the fisheries of Scotland in 2017, and the potential for them to be addressed by parasitological studies, focussing on issues in three areas:

Herring to the west of Scotland

The metapopulation of herring (*Clupea harengus*) in the North Atlantic has undergone a series of booms and busts over historical timescales. The putative stock in waters to the west of Scotland (ICES Div. VIa) which once supported a major fishery, has suffered a decline in recent years, apparently unrelated to fishing mortality, with consecutive years of recruitment failure. What can parasites tell us about the origin of the herring still found in this area, and how can this information be used by managers looking to rebuild the stock?

Mackerel distribution

Atlantic mackerel (*Scomber scombrus*) is a widely distributed small pelagic fish, and the most significant species exploited by the Scottish industry, with landings valued at around £130m in 2015. Historically, the main stock component in the Northeast Atlantic has undertaken regular migrations from the southern coasts of Norway, around the Shetland Islands, along the shelf break to the Celtic Sea, then back again, spreading out and spawning as it does so. This regular pattern has been disturbed in recent years with fish migrating to Faroes, Iceland, Greenland and the north of Norway, and spawning over a much wider area than previously. Can parasitological tags tell us anything about the significance of this change in behaviour?

Cod recovery in the North Sea

The cod (*Gadus morhua*) stock in the North Sea suffered a major crash in the late 90s and early 2000's, and was closed to targeted fishing for several years. The "stock" has undergone something of a renaissance in recent years - the biomass of the spawning stock is now above precautionary levels, and North Sea cod has received the much coveted Marine Stewardship Council accreditation. This good news story somewhat overshadows the regional aspects of the intra-stock dynamics. Cod in the North Sea previously existed as a number of discrete breeding populations, and the recovery of the stock has not been evenly distributed across components. What can parasites tell us about the composition of the "recovered" stock and how to best sustain that recovery?

3) PARASITES AS BIOLOGICAL TAGS IN SOUTH AFRICAN MARINE RESEARCH

Reed, C.C.[1, 4], Le Roux, J.[1,], Nunkoo, I.[1,4], Weston, L[1,4]., Ssempa, N[1,4]., MacKenzie, K.[2] , Ukomadu, N. [1] Sibanda, S[, 4],., Mobara A[, 4],. and van der Lingen, C.D.[3,4]

[1]Department of Biological Sciences, University of Cape Town, Private Bag X3, Rondebosch, 7701. Email: Cecile.Reed@uct.ac.za; [2]Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen AB242TZ United Kingdom; [3]Branch: Fisheries Management, Department of Agriculture, Forestry and Fisheries, Private Bag X2, Rogge Bay 8012, South Africa; and [4]Marine Research Institute, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa.

Using parasites as biological tags for fish stock discrimination has proven successful in many parts of the world. In South Africa, where this field of research has recently expanded, several commercially valuable marine fish species (*Sardinops sagax*, *Trachurus capensis*, *Merluccius capensis*, *M. paradoxus*, *Thyrsites atun*, *Genypterus capensis, Lophius* v*omerinus* and *Callorinchus capensis*) have been surveyed for parasitic infections for the purposes of using these data in population structure studies. In addition, for some species, a multi-method approach that uses a variety of stock discrimination techniques including parasite bio-tagging has proven to be useful.

The longest running and most far-reaching parasite bio-tagging project in South Africa is that done on South African sardine (*S. sagax*), considered until recently to comprise a single, panmictic population and with standard stock assessments and fishery management procedures based on this assumption. In 2010 a digenean species from the genus *Cardiocephaloides* sp. was found infecting the humors of *S. sagax* eyes. This infection showed large differences in prevalence, mean infection intensity and mean abundance between *S. sagax* caught off the west and south coasts of South Africa, indicating that the parasite's endemic area was off the west coast only. With increased sample sizes these patterns persisted throughout years, seasons and fish size classes, showing convincing evidence for the possible existence of multiple, semi-discrete stocks of *S. sagax* in South Africa. A recent PhD study that assessed the population structure of *S. sagax* using a combination of morphometric (body and otolith shape, gill arch length and gill raker spacing), meristic (vertebral number and gill raker number) and parasite biotag (*Cardiocephaloides* sp. metacercariae) stock markers further supported the multiple stock hypothesis, and found that abundance of the digenean biotag was one of the strongest discriminators between sardine from the putative western and southern stocks. Another study documented spatial differences in infection of sardine by the coccidian *Eimeria sardinae* found in the fish's testes, with fish from the putative western and southern stocks showing similar infection levels whereas no infection was observed in fish from the putative eastern stock, adding further evidence for multiple sardine stocks. This and other research has led to the development of a 2-stock assessment model for the western and southern sardine stocks that are targeted by the South African purse-seine fishery. Data on annual infection prevalence-at-length by the digenean biotag for each stock are used in this model to estimate the movement of sardine from the western to the southern stock, a novel quantitative use of bio-tag data, and have resulted in increased model precision.

Parasite biotag data has indicated multiple stocks in another commercially exploited species in South Africa, namely monk *L. vomerinus* where spatial differences in infection by a hemiurid digenean considered to be *Lecithochirium* sp. and found in the stomach have been documented. In contrast, analyses of parasite assemblages have provided inconclusive or no evidence for multiple stocks in several other fish species, including kingklip *G. capensis* snoek *T. atun*, Cape horse mackerel *T. capensis*, and St Joseph's shark *C. capensis*.

4) SEA LICE EFFECT ON WILD ATLANTIC SALMON FECUNDITY

Roman Susdorf[1,2], Nabeil Salama[2], Elvira de Eyto[3] and David Lusseau[1]

[1] University of Aberdeen, Zoology Building, Tillydrone Avenue, Aberdeen AB24 2TZ, UK
[2] Marine Scotland Science, Marine Laboratory, 375 Victoria Road, Aberdeen AB11 9DB, UK
[3] Marine Institute, Newport, Co. Mayo, Ireland

Contact corresponding author: *R.Susdorf@abdn.ac.uk*

The main economic value of wild Atlantic salmon is attributed to recreational rod fisheries, with anglers across the Atlantic spending about €500 million per year. Additional annual gross value of several millions is generated by commercial net and trap fisheries. In recent decades, wild stocks have declined globally, corresponding with climate change influences on the freshwater and marine environments.

Parasitic sea lice are ubiquitous ectoparasites infesting Atlantic salmon (*Salmo salar* L.) and feeding on host skin, mucus and blood. In Scotland, the species of interest are the salmonid specialist *Lepeophtheirus salmonis* and the generalist *Caligus elongatus*. Increase in salmon cultivation since 1960s has escalated host and parasite densities, leading to the interest in sea lice – wild salmonid interactions in Scottish coastal waters and elsewhere due to their potential impact on wild salmon returns.

Laboratory experiments demonstrate that sea lice can elicit sub-lethal effects causing physiological stress, a reduction in growth and body condition. Furthermore, reports indicate parasitism may influence marine survival.

We evaluated the influence of sea lice parasitism on body condition of returning salmon using a model accounting for variables year and parasite density (mobile sea lice/kg). Using salmon data from Strathy Point (N Scotland, 1999-2007), we show that sea lice reduce condition (residuals of the $\log_{10}$(length)-$\log_{10}$(weight)-relationship) by median 0.017 (95% CI: 0.003-0.047), corresponding to a mass loss of 4 % (0.63-11.4) or 92 g (16-272). Applying this condition effect to data for female salmon indicates an ova reduction by median 3.7 % (2.2-6.2) in 1SW and 3.2 % (-0.6-20.1) in MSW. However, a concern with sampling returning salmon is that only fish surviving the marine phase can be recorded. Being more likely to die at sea, fish in poor condition (potentially highly infested) are underrepresented. Thus it is crucial to note, that the described effect from sea lice on condition (and thus fecundity) is likely underrated.

This is the first study revealing a non-lethal impact from sea lice in wild Atlantic salmon. Furthermore, we also derive a useful proxy (i.e. condition) for fecundity incorporating both fish weight and length, which can improve current management practise. We show that a sea lice-mediated condition-effect has the potential to diminish Atlantic salmon stock components and thus can influence population dynamics.

5) DEVELOPING A METHOD TO INVESTIGATE INFESTATION PRESSURE FROM SEA LICE ON MIGRATORY SALMONIDS UTILISING TOWED & STATIC SENTINEL CAGES

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A number of studies have linked sea lice from fish farms to heavy infestations of wild salmonids and subsequent population declines in marine aquaculture areas (Butler 2002; Vøllestad 2009; Middlemas et al. 2010). However, no study has ever been carried out to design and deploy equipment to measure the specific infestation pressure salmon smolts may experience from sea lice as they enter the marine environment and migrate down a sea loch towards the open sea in a region containing Atlantic salmon aquaculture.

A methodology to simulate sea lice infestation pressure experienced by salmonids migrating through the marine environment may be possible utilising towed sentinel cages. Towing cages of Atlantic salmon could be used to determine specific points of infestation along the migratory route where fish are at risk and as a result the possible source(s) of infectious lice.

Prototype towable sentinel cages containing 50 Atlantic salmon were field tested in Loch Linnhe, located on Scotland's west coast. Additionally, "traditional" fixed location sentinel cages were also deployed to allow an estimate of the infestation pressure level in the area of loch where the pilot study was carried out and allow us to compare the methodologies. The towed net system consisted of a Bongo net frame fitted with 2 x 1 m diameter plastic drums with attached plankton net, CTD to measure oceanographic parameters and a Go-Pro camera to record both the performance of the nets and fish behaviour. Additional oceanographic data was collected using a Vessel Mounted Acoustic Doppler Current Profiler (VMADCP) collecting current data underneath the ship and CTD "dips" to evaluate temperature and salinity changes with depth.

Over the week a total of 139 sea lice were isolated from all methodologies deployed during the pilot study. In total eight towed sentinel cage transects were carried out, two sentinel cages deployed and recovered with eight complimentary plankton tows taken during the deployment of the towed sentinel cages. On a methodology specific basis 129 lice were isolated from fixed sentinel cages, 6 lice from towed sentinel cage fish, and 4 from complimentary plankton sampling. The mean number of lice/hour sampled were calculated by method which showed - fixed sentinel cages 1.28, towed cages 0.86 and plankton trawls 0.93. CTD data from all eight tows showed temperature and salinity variations during the tow as well as pressure variations due to the vertical movement of the cage. The pressure data showed the vertical location of the cage within the water column; while during a first trial the cage sank to 8.6 m, during all subsequent tows the cages stayed between 2.0 m and 3.0 m as planned. CTD "dips" were carried out at four locations and VMADCP data collected for nine designated transects.

Overall the main aim was successfully achieved with the towed array successfully deployed from the vessel and sea lice found infesting the fish. However, issues with a combined plankton net with a cod end attached to a pump and towed sentinel cage system were found to be largely unworkable and will be discontinued in future trials and instead a 40 cm diameter bongo net will be deployed next to the towed sentinel cages for 10 min per hour.

In summary this is preliminary work but clearly demonstrates that sea lice will settle on salmon in towed cages although greater number settled on salmon in "traditional" fixed sentinel cages. These findings have informed development of the methodology for further work in 2016 with towing speed thought to be a crucial factor for lice settlement.

6) SURVEY OF KING SCALLOPS (*Pecten maximus*) FOR THE PRESENCE OF APICOMPLEXAN PARASITE IN SCOTLAND

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The King scallop, *Pectin maximus*, is the second most valuable commercially exploited mollusc in Scotland with landings fluctuating between 9,000 – 10,000 tonnes over the last decade. The majority of the landings in the UK are exported to France, Italy and Spain with an export value of £90 million in 2012. An Apicomplexan-like parasite was associated with abnormal mortality in Iceland scallops (*Chlamys islandica*) and consequent collapse of the stock. Although no mortality records were reported in Scotland, the Icelandic researchers found an identical parasite on Scottish scallops during the research.

7) RED VENT SYNDROME IN ATLANTIC SALMON (*Salmo salar* L.): DO DIETARY INPUTS AND PARASITIC COMPONENT COMMUNITIES OF SALMON POPULATIONS REFLECT DIFFERENT MIGRATORY ROUTES?

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In 2005, Atlantic salmon (*Salmo salar* L.) migrating to the UK exhibited swollen, haemorrhagic vents, symptoms not previously recorded. The condition was latterly termed Red Vent Syndrome (RVS), with these symptoms subsequently observed in Canada, Iceland and Ireland. RVS has been pathognomonically associated with one of the most abundant parasites within the marine environment, the ascaridoid *Anisakis simplex*, which causes Anisakiasis in humans. Although A. simplex is commonly found in S. salar, infestation of the vent region is novel and the expression of RVS has not been prevalent in other fish species. Despite the proposal of various hypotheses, the definitive causes of RVS remain unknown.

As part of a study carried out at Napier University in conjunction with Marine Scotland we have i) determined the nematode burden and location of infestation in salmon sampled from East, West and North Scottish coasts through full parasitic examinations, ii) assessed whether migration routes influence dietary composition using stable isotope analysis of muscle tissue and scales, and iii) clarified the presence of any differences in parasitic communities between populations of Atlantic salmon. Preliminary results indicate a significant relationship between the total number of nematodes in the vent region and the rest of the body ($F=98.04$, $df=1$, $p<0.001$). Stable isotopes however showed no significant differences in dietary composition between populations (scales: $F=0.63$, $p=0.641$, Wilk's $\Lambda=0.951$; muscle: $F=1.57$, $p=0.182$, Wilk's $\Lambda=0.946$).

Significant differences between parasitic communities were observed between Atlantic salmon sampled from the East and North coasts of Scotland ($F=4.889$, $df=2$, $p<0.0005$), with the primary driver being *Anisakis simplex* abundance (SIMPER; 41.59%).The relationship between nematode burdens in the vent and the body supports the 'hyper-infestation' hypothesis and could signal increasing numbers of A. simplex in British waters. While the different capture locations of the salmon are not reflected by differences in dietary compositions, the significant differences in parasitic communities between East and North populations suggest that migratory routes of these populations differ.

8) PARASITES AS INDICATORS OF POPULATION STRUCTURE OF SNOEK (*THYRSITES ATUN*) IN THE BENGUELA ECOSYSTEM

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Thyrsites atun (Euphrasen, 1791) is a medium-sized, schooling, predatory gempylid native to temperate coastal waters of the southern hemisphere. Off South-West Africa, *T. atun* occurs in both the northern and southern sectors of the Benguela upwelling ecosystem where it is a socio-economically important species. While its biology has been well studied, how many *T. atun* stocks occur in the Benguela ecosystem is still debatable. The population structure and movements of *T. atun* off south western Africa have been investigated employing a number of indicators such as catch data, tagging studies, analysis of spatial and temporal distribution, diet, distribution of eggs, larvae and juveniles as well as life history traits. Nonetheless, the results have so far not been conclusive enough to allow a delineation of discrete stocks.

A survey of the metazoan parasite fauna of *T. atun* in the Benguela (n = 339) revealed 16 parasite taxa. The compound community of *T. atun* caught in the northern Benguela was less speciose and was nested within that of *T. atun* from the southern Benguela. Two long-lived parasite taxa (*Anisakis* spp., *Molicola uncinatus*) were selected as potential biological tags and their host-parasite relationships were examined by means of Generalized Linear Models (GLMs). The analyses revealed significant ($p < 0.05$) spatial variability in the rates of accumulation and abundance at a given host size for both parasite taxa, supporting a two stock hypothesis for *T. atun* in the Benguela ecosystem.

List of Attendees (Day 1 & 2)

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