



Measuring and managing invasive species threats in the Arctic

by

Chris Ware

B. Sc (Hons)

Thesis submitted in partial fulfilment of the requirements for the degree of PhD

University of Tasmania

School of Geography and Environmental Studies

University of Tasmania

March 2014

Declaration of originality

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

Chris Ware



Date 31 March 2014

Statement of authority of access

The publishers of the papers comprising Chapters 2 and 5 hold the copyright for that content, and access to the material should be sought from the respective journals. The remaining non published content of the thesis may be made available for loan and limited copying and communication in accordance with the Copyright Act 1968

Chris Ware



Date 31 March 2014

Statement of Ethical Conduct

The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

Chris Ware



Date 31 March 2014

Statement of co-authorship

The following people and institutions contributed to the publication of work undertaken as part of this thesis:

Chapter 2: Ware C, Bergstrom DM, Müller E, Alsos IG (2012) Humans introduce viable seeds to the Arctic on footwear. *Biological Invasions*, 14(3), 567-577.

Chris Ware, School of Geography and Environmental Studies / University Centre on Svalbard, Norway

Dana Bergstrom, Australian Antarctic Division

Eike Müller, University Centre on Svalbard, Norway

Inger Greve Alsos, Tromsø University Museum, Norway

Author contributions: IGA conceived idea, all authors contributed to project design, CW and EM carried out sampling, laboratory work and data analysis, CW wrote the manuscript with input from all authors.

CW (candidate) (60%), IGA (20%), EM (15%), DMB (5%)

We the undersigned agree with the above stated "proportion of work undertaken" for the above published peer-reviewed manuscripts contributing to this thesis:

Signed: _____

(James Kirkpatrick)
Supervisor
School Of Geography
and Environmental Studies
University of Tasmania

(Name)
Head of School
School of Geography
and Environmental Studies
University of Tasmania

Date: _____

Chapter 3*: Alsos IGA, Ware C, Elven R (submitted manuscript) Past Arctic aliens passed away, current ones may stay.

Author contributions: IGA conceived research questions and project design, IGA, CW, and RE conducted sample collection, RE led the taxonomic revisions with input from IGA, IGA assembled and analysed the data with CW, IGA wrote the manuscript with input from all authors.

CW (candidate) (30%), IGA (60%), RE (10%)

* Contributions for this work are concluded here as I was not the primary author.

Chapter 5: Ware C, Kirkpatrick, JB, Sundet JH, Jelmert A, Berge J, Coutts ADM, Floerl O, Pellissier L, Wisz MS, Alsos IG (2014). Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. *Diversity and Distributions*, 20(1), 10-19.

Chris Ware, School of Geography and Environmental Studies / Tromsø University Museum, Norway

James Kirkpatrick, University of Tasmania, Sandy Bay, Tasmania, Australia

Jan Sundet, Institute of Marine Research, Norway

Anders Jelmert, Institute of Marine Research, Bergen, Norway

Jørgen Berge, University of Tromsø / University Centre on Svalbard, Norway

Ashley Coutts, Biofouling Solutions PTY LTD, Kingston, Tas., Australia

Oliver Floerl, SINTEF Fisheries & Aquaculture, Trondheim, Norway

Steffen Olsen, Danish Meteorological Institute, Denmark

Loïc Pellissier, Aarhus University, Denmark

Mary Wisz, Aarhus University, Denmark / Greenland Institute of Natural Resources, Greenland

Inger Greve Alsos, Tromsø University Museum, Norway

Author contributions: CW and IGA conceived research questions and project design, SMO, MW, and LP provided environmental data, CW assembled and analysed data with advice from JBK and OF, and CW wrote the manuscript with input from all authors.

CW (candidate) (70%), JBK (10%), IGA (10%), remaining authors together (10%)

We the undersigned agree with the above stated “proportion of work undertaken” for the above published peer-reviewed manuscripts contributing to this thesis:

Signed: _____

(James Kirkpatrick)
Supervisor
School Of Geography
and Environmental Studies
University of Tasmania

(Name)
Head of School
School of Geography
and Environmental Studies
University of Tasmania

Date: _____

Abstract

Several decades of invasive species research have yielded a broad understanding of the nature of species transfer mechanisms and associated threats globally. This is not true of the Arctic, however, a region where increasing human activity and ongoing climate change is expected to promote species invasion. This thesis examines the potential for both terrestrial and marine non-indigenous species (NIS) to be introduced to and establish in the Arctic under present and future climatic conditions. Throughout, the work uses the high-Arctic archipelago Svalbard as a model for the wider Arctic region. The research focuses on two of the most well-described pathways of species introduction globally, human visitation and shipping, both of which are increasing in intensity in Svalbard. Potential for species introduction and establishment is examined by quantifying and identifying propagule loads transferred to the Arctic; developing and testing species identification methods; evaluating present and forecasting future habitat suitability for NIS; measuring the spread of established non-indigenous vascular plants; and testing the efficacy of management measures designed to prevent further species introduction.

Results demonstrate high plant propagule transport by people travelling to highly-visited Arctic regions is occurring. Furthermore, propagule pressure associated with ship hull fouling poses immediate risks, while if more stringent management related to ships' ballast water discharge is not enacted this vector will pose an increasing risk over the coming century. Improved vector screening methods were achieved through testing a molecular species identification approach for organisms transported with ships, but the approach was found to be inefficient in a biosecurity management context. Climate changes, and particularly temperature increases, over the coming century are expected to increase Svalbard habitat suitability for both terrestrial and marine species. Acknowledgment of the negative impacts NIS may have in Svalbard has led to the implementation of preventative management measures designed to reduce species transfer by visitors and ships; however, these were found to have limited effect. Scope for improved management is outlined.

Where species invasion risks are found to exist at the transport stage, the body of invasion ecology knowledge suggests a precautionary approach whereby NIS introduction should be prevented. The imperative to ensure this in polar regions has historically been lacking, owing largely to the strength of climatic barriers, and assumed weak propagule pressure. By quantifying propagule pressure across different pathways and vectors, and estimating changing habitat suitability under forecast climatic conditions, this research provides the basis upon which to develop more informed biosecurity management for Svalbard. Moreover, given the similarity in pathways of species introduction across the Arctic region, the work presented here suggests an Arctic-wide need to address management and policy gaps.

Acknowledgements

A number of people and organisations have provided advice, assistance, and support through the course of this work. I wish to gratefully acknowledge and thank them for their contribution.

My Norwegian supervisor, Inger Greve Alsos, deserves particular acknowledgment for her continued support in facilitating and supervising the project work that constitutes this thesis. Given the substantial amount of her time required to organise an Australian to undertake this work in Norway, and the onerous task placed on her of swiftly becoming a marine ecologist, her support in, and commitment to this project was absolutely fundamental.

My gratitude is also extended to the University Centre on Svalbard, and the Tromsø University Museum where Inger was employed during my candidature. My project evolved dynamically, and had the resultant support granted by the Tromsø University Museum been foreseeable at the outset of my studies, more formal recognition of this institute's contribution to my studies would have been sought.

I wish to thank also my Australian supervisor, Jamie Kirkpatrick, for continued advice, assistance, and perceptiveness, which greatly benefited the development of this thesis.

The funding support of the Svalbard Environmental Fund (Chapters 2-5, 7) and of the Fram Centre (Chapters 5-7) is gratefully acknowledged.

The assistance of Store Norsk and the Svalbard Sysselmannen is gratefully acknowledged for providing air transport and accommodation to support ballast water sampling. In addition I would like to thank the Russian coal mining company Arktikugol and the shipping companies Norden and the Murmansk Shipping Company, for their assistance and cooperation in ballast water sampling.

The support and assistance rendered by Ilja Lang and Frigg Jørgensen from the Association of Arctic Expedition Cruise Operators (AECO) to the development and conduct of work undertaken for Chapter 3 is gratefully acknowledged.

The AECO members, Quark, Oceanwide, Spitsbergen Travel, Silversea Expeditions, GAP, and their respective expedition staff, are gratefully acknowledged for their cooperation in collecting samples and participating in research that contributed to chapters 2, 4 and 5.

I wish to thank a number of people who offered their expertise throughout the course of this research (Georgy Semenov, Ole Aardbakke, Oli Floerl, Ashley Coutts, Darren Kriticos, Slawek Kwasniewski, Andrey Sikorski, Elisabeth Larson, and Dean Paini).

I would also like to thank Dean Paini for organising office space at CSIRO for the concluding months of my PhD.

Finally, I wish to thank my partner, Sarah. It wouldn't have worked with anyone else.

Table of Contents

1. Measuring and managing invasive species threats in the Arctic: general	
introduction	1
Why measure and manage invasive species?	1
Is it possible to predict which species will become invasive?	3
How to organise research around identifying and managing risks of species	
Introduction?	4
Invasive species in the Arctic	6
Measuring and managing invasive species threats in the Arctic	8
Thesis outline	9
Study site	10
References	11
2. Humans introduce viable seeds to the Arctic on footwear	20
Abstract	21
Introduction.....	22
Methods	23
Results	25
Discussion	29
References	31
3. Past Arctic aliens have passed away, current ones may stay	37
Abstract	38
Introduction.....	39
Methods	40
Results	41
Discussion	43
Conclusion	45
References	45
4. The efficacy of footwear disinfection to prevent microbial species introduction	
to the Arctic	50
Abstract	51
Introduction.....	52
Methods	53
Results	54
Discussion	55
Conclusion	57
References	57

5. Climate change, non-indigenous species, and shipping: assessing the risk of species introduction to a high-Arctic archipelago	63
Abstract	64
Introduction.....	65
Methods	66
Results	68
Discussion	72
Conclusion	75
References	76
6. Applicability of universal primers for identifying zooplankton in ship ballast water.....	81
Abstract	82
Introduction.....	83
Methods	84
Results	87
Discussion	90
Conclusion	93
References	94
7. Is marine species invasion a threat to a warming Arctic?.....	98
Abstract	99
Introduction.....	100
Methods	102
Results	105
Discussion	111
Conclusion	113
References	114
8. Synthesis	122
Perspectives.....	126
9. Appendix 1	127
10. Appendix 2	135
11. Appendix 3	142