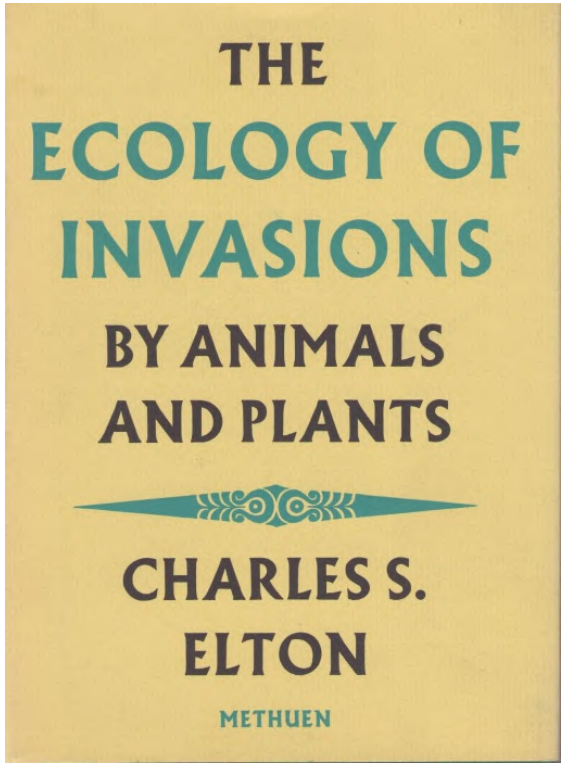
Biotic Resistance from Native Predators Predicts Mosquito Invasion Success and Informs Biocontrol Strategies

Ross N. Cuthbert, Amanda Callaghan, Jaimie T. A. Dick

Biotic resistance hypothesis



Communities resist invasion *via* **predation**, **competition**, **parasitism**, **disease** and **aggression**

Greater diversity = **higher resistance**

Parallels between **invasion** and **biocontrol** sciences

- Invasion: biotic resistance **regulates invader success (?)**
- Biocontrol: biotic resistance **controls pests**

Biocontrol & invasion parallels

Biocontrol agent success/failures in novel range often recorded

Drivers have parallels to understanding **invasion success**

Invasion science **lacks predictive/quantitative measures** for success

Plant Pathology

Free Access

Biological Control of Weeds. A World Catalogue of Agents and their Target Weeds.

M. H. Julien and M. W. Griffiths (eds). 21 × 29.5 cm, 223 pp. UK, Wallingford: CAB International [http://www.cabi.org]. 1998. £27.50. ISBN 085199 234 X (paperback).

Morag Webb

OIKOS

SYNTHESISING ECOLOGY

Full Access

The elephant in the room: the role of failed invasions in understanding invasion biology

Rafael D. Zenni, Martin A. Nuñez

First published: 24 January 2013 | https://doi.org/10.1111/j.1600-0706.2012.00254.x | Cited by: 117

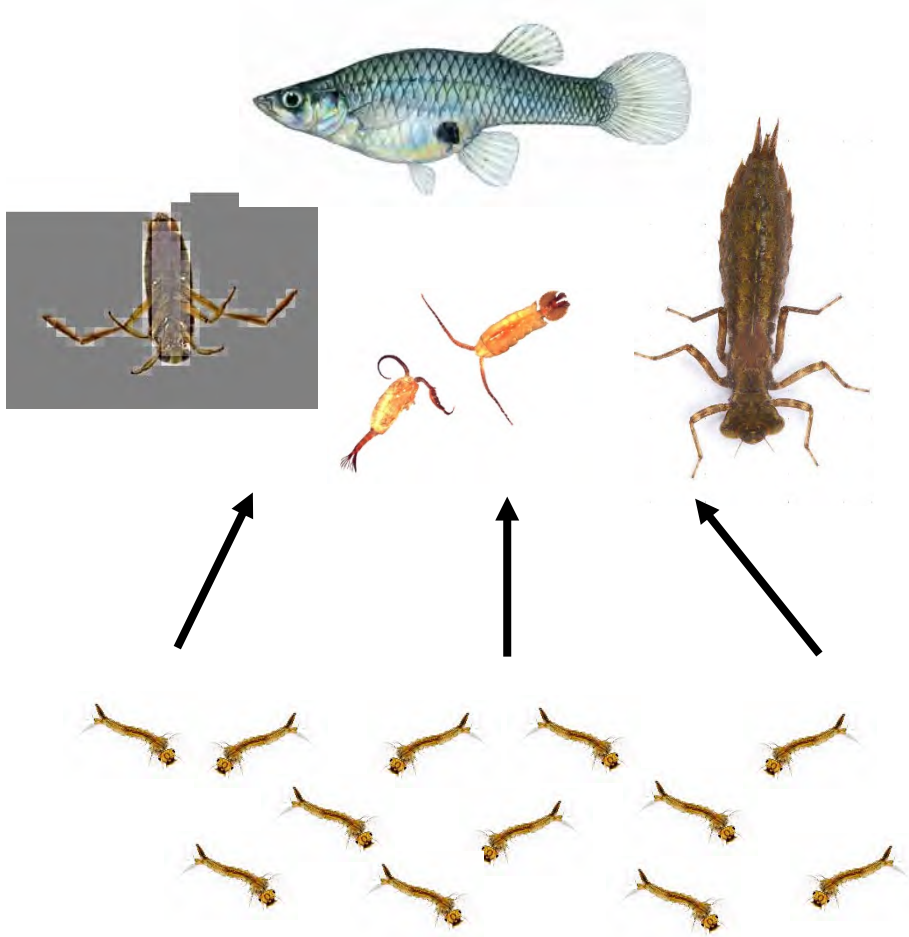
Mosquito control: bridging invasion and biocontrol sciences

Deadliest animals in world

- **435,000 deaths** from **malaria/yr** (WHO, 2018)

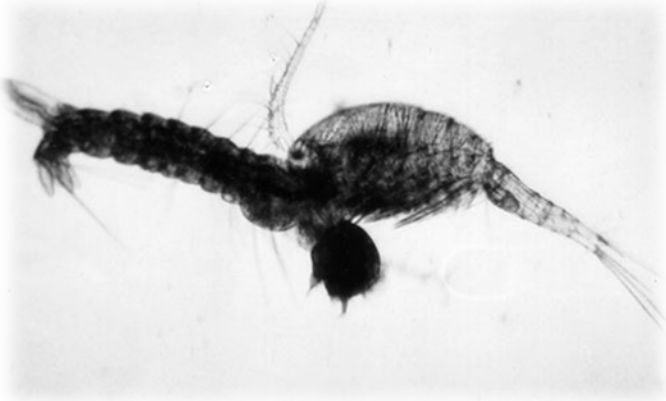
Many highly **invasive pest** species which also cause **disease**

Aquatic life stages suffer high biotic resistance



Copepods and mosquito control

- Most successful predatory natural enemy
  - e.g. **community-scale dengue vector elimination**



- **Widespread**, **diverse** and **abundant**

- Tolerate **minute, ephemeral systems** unlike other predators

Calanoid Copepods: An Overlooked Tool in the Control of Disease Vector Mosquitoes

Ross N Cuthbert ✉, Tatenda Dalu, Ryan J Wasserman, Amanda Callaghan, Olaf L F Weyl, Jaimie T A Dick

Journal of Medical Entomology, Volume 55, Issue 6, November 2018, Pages 1656–1658,

New strategy against *Aedes aegypti* in Vietnam

Brian Kay, Vu Sinh Nam

Asian tiger mosquito (*Aedes albopictus*)

Most invasive mosquito species globally

- > 25 European countries
- **Drought-/freeze-resistant eggs**
- Exploits **minute container-style habitats**

Major **threat to public health**

- **Zika, dengue, chikungunya**

Superior larval resource competitor

…but often fails to displace natives

Biotic resistance mediates success?

Recent UK arrival

EXPRESS
Home of the Daily and Sunday Express

UK disease WARNING: Aggressive tiger mosquitoes to invade UK bringing dengue fever & Zika

CORRESPONDENCE | VOLUME 17, ISSUE 2, P140, FEBRUARY 01, 2017

Detection of the invasive mosquito species *Aedes albopictus* in southern England

Jolyon M Medlock • Alexander GC Vaux • Benjamin Cull • Francis Schaffner • Emma Gillingham • Valentin Pfluger • et al. Show all authors

Published: February, 2017 • DOI: https://doi.org/10.1016/S1473-3099(17)30024-5

Killer mozzie alert: Britain facing INVASION of mosquitoes carrying deadly diseases

BRITAIN faces an invasion by record numbers of Asian tiger mosquitoes carrying deadly diseases because of the balmy weather, say experts.

By Laura Neil / Published 19th April 2018

THE Sun

VAMPIRE BUGS Fears Asian tiger mosquitoes that carry dengue fever, West Nile virus and Zika to invade UK this summer

Quantifying biotic resistance

Applying **classic ecological concepts**

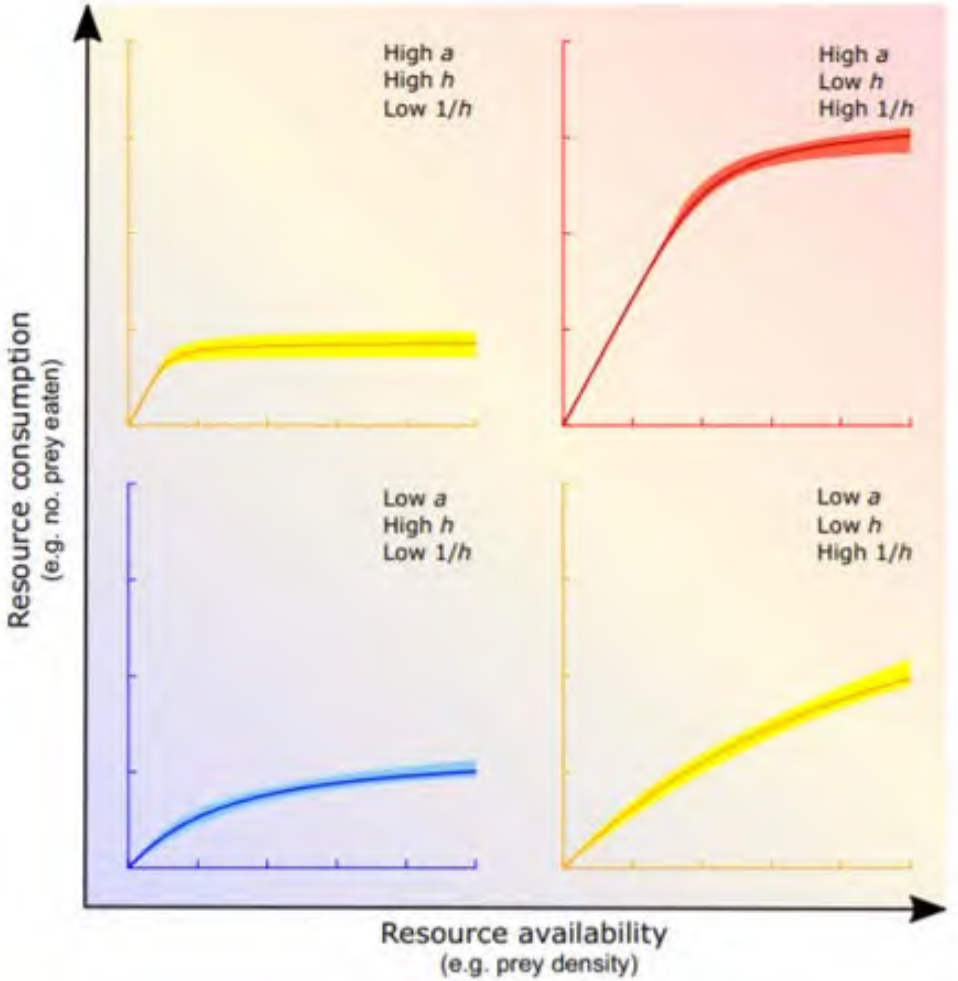
(1) <u>Functional Response (FR)</u>

- resource use ~ resource density

Key parameters predict *per capita* ecological impact: **attack rate** (*a*), **handling time** (*h*)

- High *a*, low *h* = high impact

FR Ratio (FRR): *a*/*h*



Cuthbert *et al*. (2019) *Biol. Invasions*

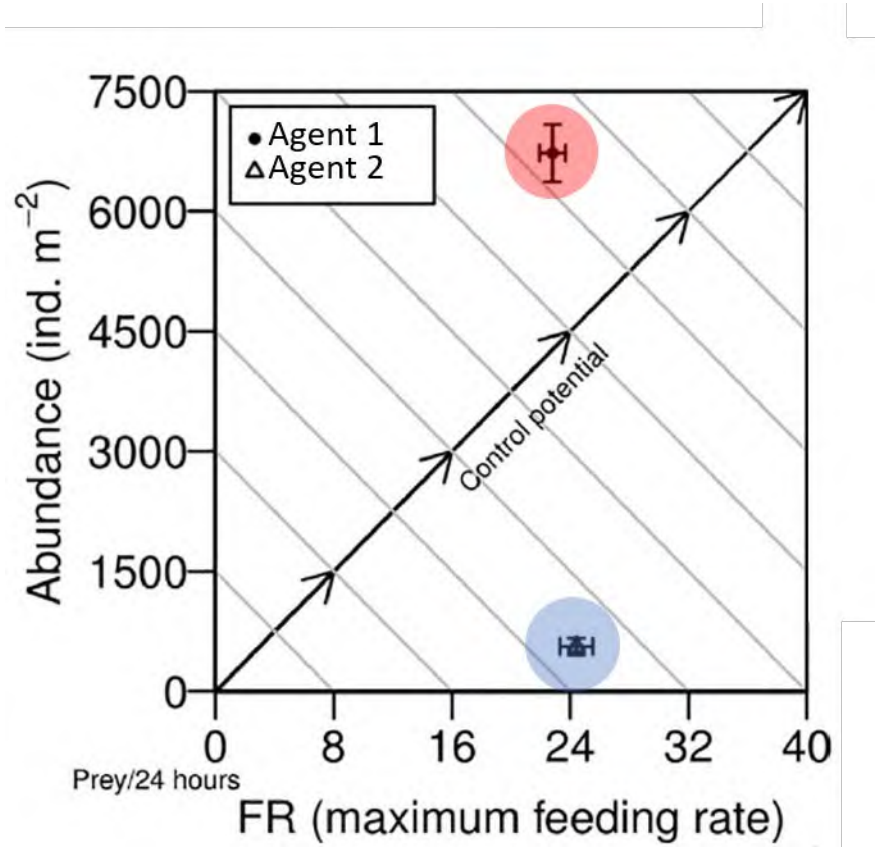
Quantifying biotic resistance

(2) <u>Numerical Response (NR)</u>

- predator aggregation ~ prey density
- NR × FR = **Total Response** (TR)

NR **proxies** (e.g. predator abundance, fecundity)

High FR & NR = high **population-level biotic resistance**



Comparing biocontrol agents:
Relative Control Potential

Cuthbert *et al*. (2018a, b) *Biol. Control*

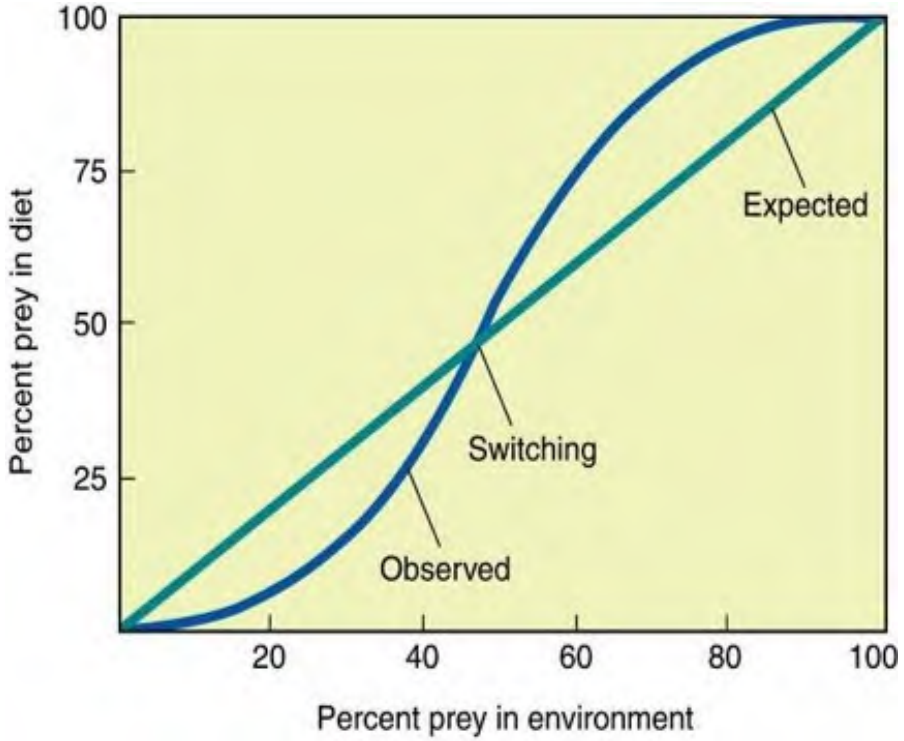
Quantifying biotic resistance

(3) Prey preferences & switching

- predation rate ~ prey frequency

Switching among prey is **stabilising mechanism** (Murdoch 1969)

Frequency-independent preferences = **high biotic resistance**




Marine Environmental Research

Using functional responses and prey switching to quantify invasion success of the Pacific oyster, *Crassostrea gigas*

Patrick W.S. Joyce, James W.E. Dickey, Ross N. Cuthbert, Jaimie, T.A. Dick, Louise Kregting


SCIENTIFIC REPORTS

OPEN

Intermediate predator naïveté and sex-skewed vulnerability predict the impact of an invasive higher predator

Quantifying biotic resistance

Frequency-independent preference
for **native** mayfly **over invasive** shrimp

Aligns with **field patterns of success**

ROYAL SOCIETY OPEN SCIENCE

rsos.royalsocietypublishing.org

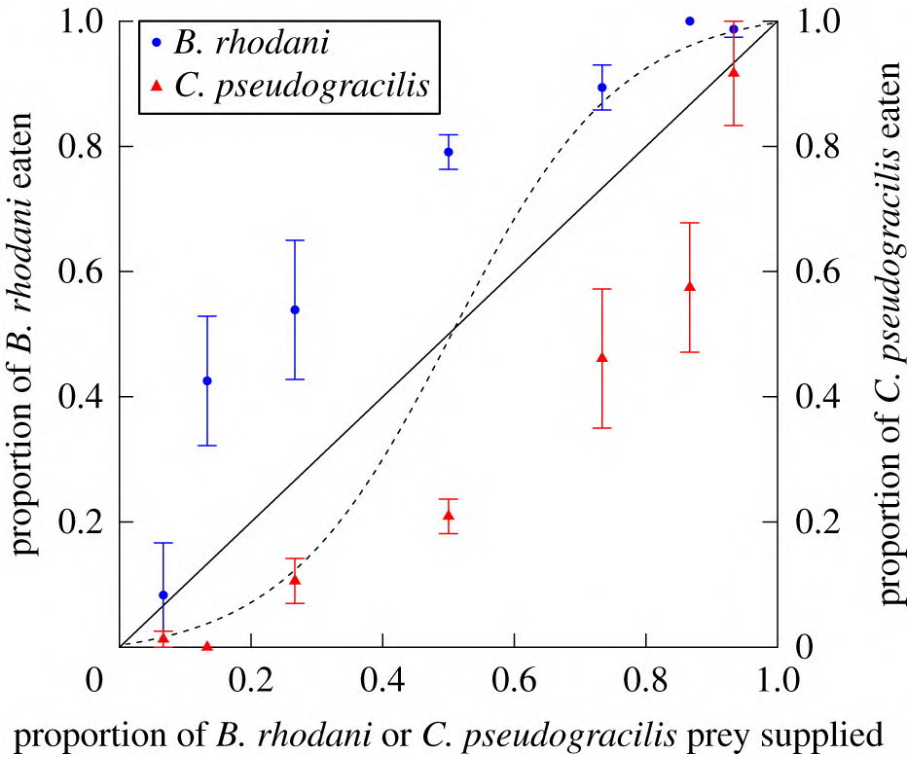
Research

Cite this article: Cuthbert RN, Dickey JWE, McMorrow C, Laverty C, Dick JTA. 2018 Resistance is futile: lack of predator switching and a preference for native prey predict the success of an invasive prey species. *R. Soc. open sci.* **5**: 180339. http://dx.doi.org/10.1098/rsos.180339

Resistance is futile: lack of predator switching and a preference for native prey predict the success of an invasive prey species

Ross N. Cuthbert, James W. E. Dickey, Clare McMorrow, Ciaran Laverty and Jaimie T. A. Dick

Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Medical Biology Centre, 97 Lisburn Road, Belfast BT9 7BL, UK



Study system

Biotic resistance compared between larval **invasive *A. albopictus*** and **native *Culex pipiens***

By three **native predatory copepods**

- *Macrocyclops albidus*, *Macrocyclops fuscus*, *Megacyclops viridis*

Laboratory mesocosm **feeding experiments**

(1) FRs (single prey species, different densities)

(2) Switching (both prey species, different ratios)

Aedes albopictus (invader)

Culex pipiens (native analogue)

General methods

Starve predators to **standardise hunger** (24 h)

Introduce predators into arenas containing one of a **range of prey densities/proportions** for fixed feeding time

(1) **FRs**: Determine **Type**; fit appropriate **model**; non-parametric **bootstrapping** to compare curves

(2) **Switching**: fit/examine **preference model** across prey proportions

Invader/native biotic resistance

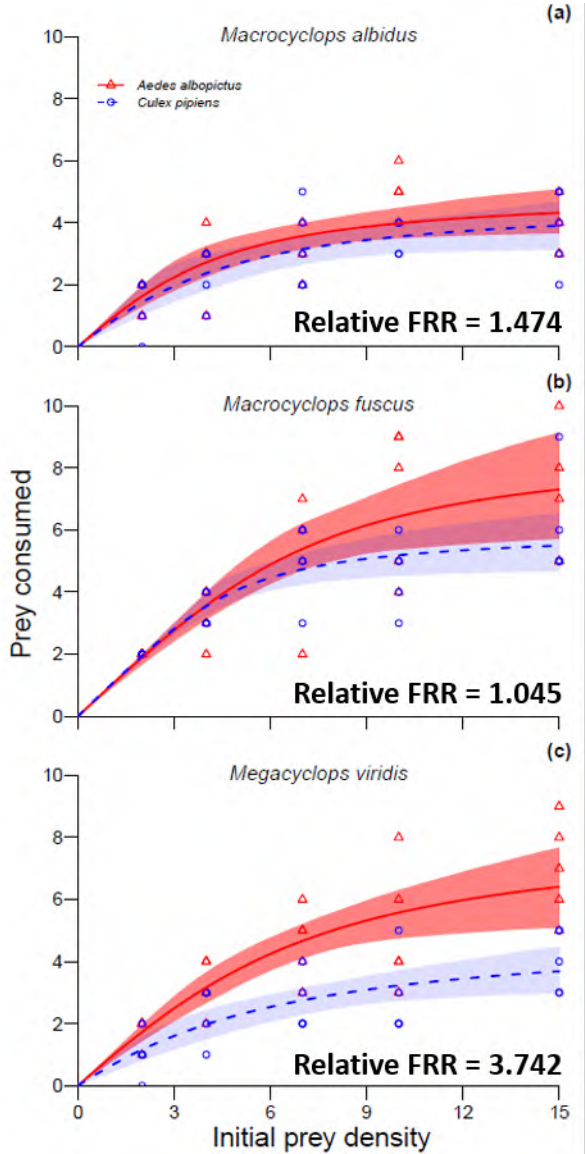
(1) FRs

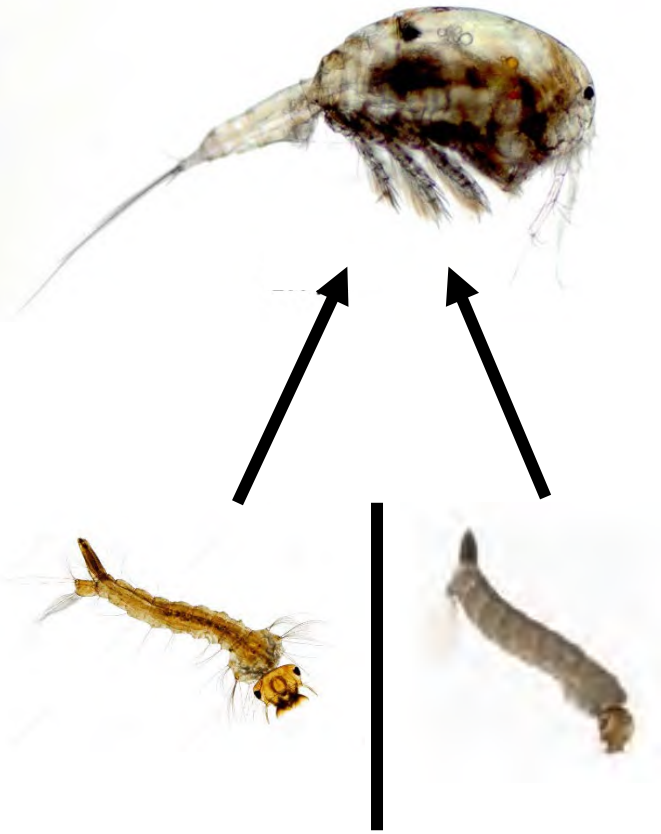
Consistently **higher FR** magnitude **towards invader**

Invader/native **FRR** calculated (*a*/*h*)

- Relative FRR = FRRi/FRRn

FRR **always higher** towards **invader** by all native predators





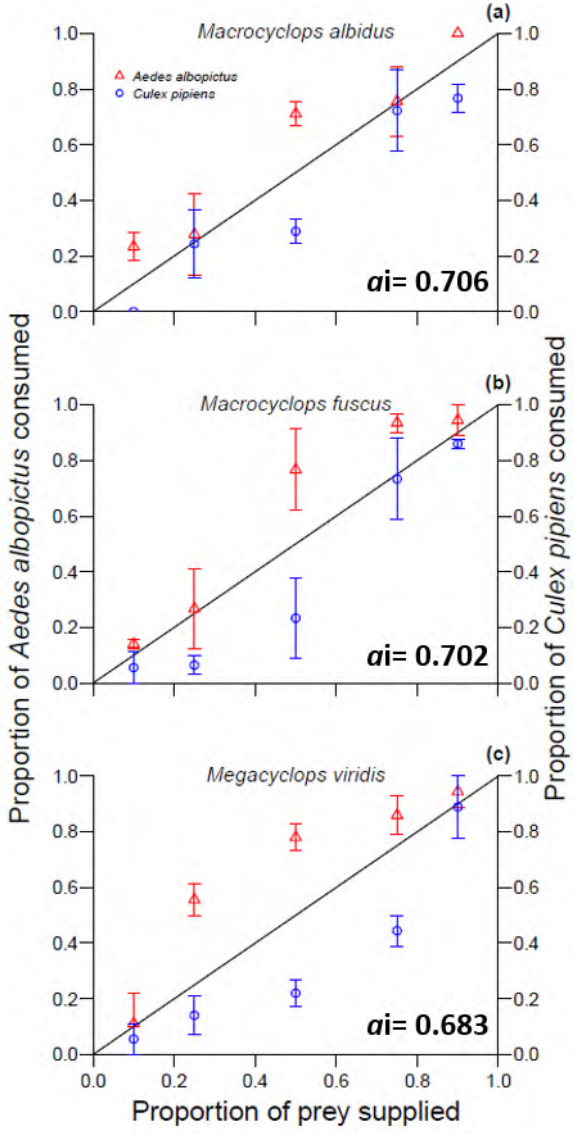
Invader/native biotic resistance

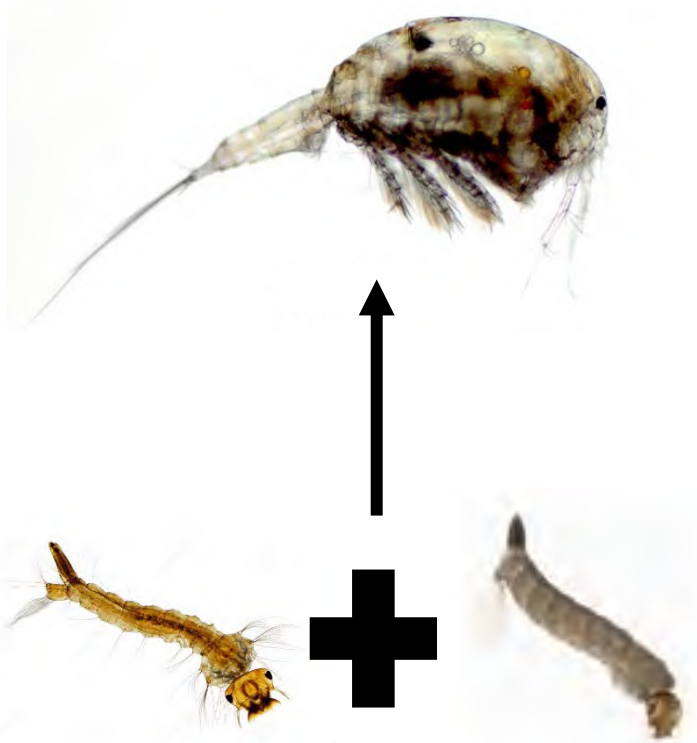
(2) Switching

Consistent **preference for invader** over native mosquito

Predators **did not switch** from invader

Invader preference indices calculated (*a*i, Manly, 1974)





Comparing predator efficacy: Biotic Resistance (BR) potential

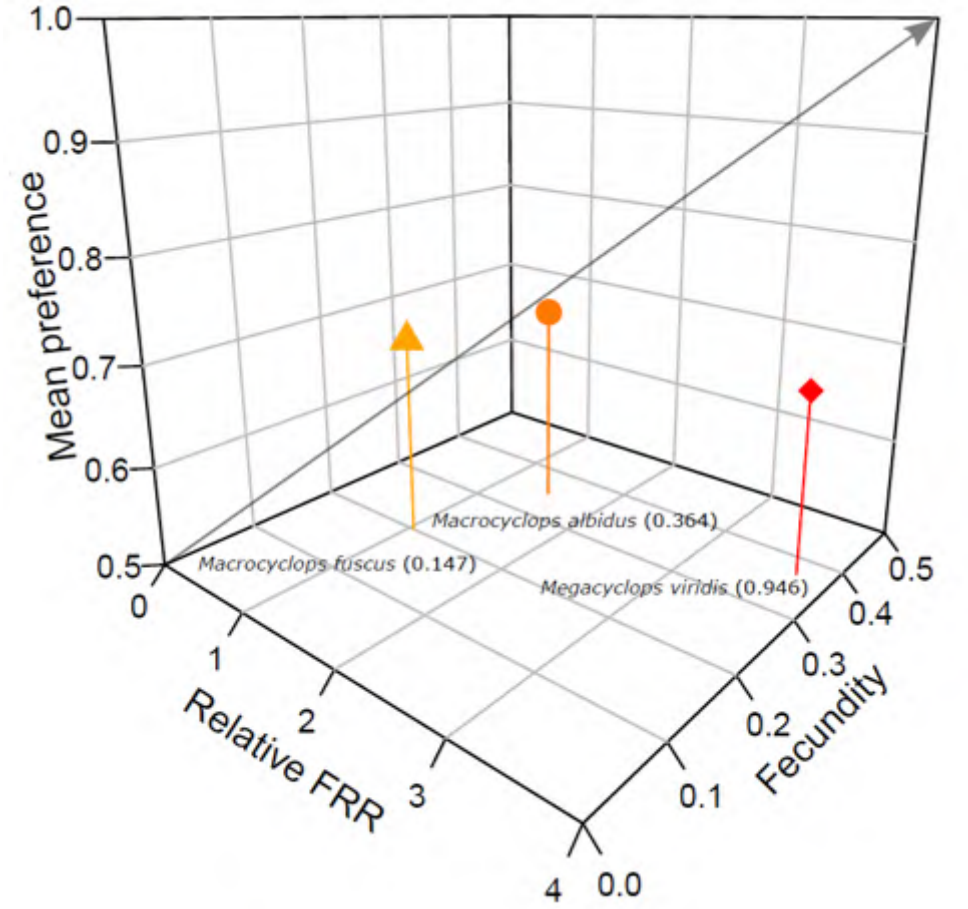
(3) NRs

Copepod **fecundity** (reproductive effort) used as **proxy**

BR = Relative FRR x *α*i x NR

Differential impacts

- *M. viridis* > *M. albidus* > *M. fuscus*



Cuthbert *et al*. (2019) *Sci. Rep.*

Synthesis

All **native predators** displayed:

(1) Consistently **higher FR(R) towards invader** over native;
(2) Frequency-independent **preference for invader**

Differential biotic resistance may limit *A. albopictus* **invasion success**

BR a novel metric to **compare natural enemies** for biocontrol

Field patterns

Aedes albopictus frequently **fails to displace native mosquitoes**

Behaviour, naïveté?

Resident predators may **offset competitive advantage**

Invasion success predictable in this system, and likely for other **habitats/taxa**

Oecologia (2008) 155:631–639
DOI 10.1007/s00442-007-0935-4

COMMUNITY ECOLOGY - ORIGINAL PAPER

Do natural container habitats impede invader dominance? Predator-mediated coexistence of invasive and native container-dwelling mosquitoes

Banugopan Kesavaraju · Kavitha Damal · Steven A. Juliano

Biological Invasions **3**: 151–166, 2001.

Testing predictions of displacement of native *Aedes* by the invasive Asian Tiger Mosquito *Aedes albopictus* in Florida, USA

L.P. Lounibos[1,*], G.F. O'Meara[1], R.L. Escher[1], N. Nishimura[1], M. Cutwa[1], T. Nelson[1,3], R.E. Campos[1,4] & S.A. Juliano[2]

Output

SCIENTIFIC REPORTS
nature research

OPEN

A novel metric reveals biotic resistance potential and informs predictions of invasion success

Ross N. Cuthbert[1,2*], Amanda Callaghan[2] & Jaimie T. A. Dick[1]

Invasive species continue to proliferate and detrimentally impact ecosystems on a global scale. Whilst impacts are well-documented for many invaders, we lack tools to predict biotic resistance and invasion success. Biotic resistance from communities may be a particularly important determinant of the success of invaders. The present study develops traditional ecological concepts to better understand and quantify biotic resistance. We quantified predation towards the highly invasive Asian tiger mosquito *Aedes albopictus* and a representative native mosquito *Culex pipiens* by three native and widespread cyclopoid copepods, using functional response and prey switching experiments. All copepods demonstrated higher magnitude type II functional responses towards the invasive prey over the analogous native prey, aligned with higher attack and maximum feeding rates. All predators exhibited significant, frequency-independent prey preferences for the invader. With these results, we developed a novel metric for biotic resistance which integrates predator numerical response proxies, revealing differential biotic resistance potential among predators. Our results are consistent with field patterns of biotic resistance and invasion success, illustrating the predictive capacity of our methods. We thus propose the further development of traditional ecological concepts, such as functional responses, numerical responses and prey switching, in the evaluation of biotic resistance and invasion success.

Output

INVASIVESNET

Management of Biological Invasions (2020) Volume 11 **Article in press**

CORRECTED PROOF

Research Article

In for the kill: novel biosecurity approaches for invasive and medically important mosquito species

Ross N. Cuthbert[1,2,3,*], Eoghan M. Cunningham[1,2], Kate Crane[1,2], Jaimie T.A. Dick[1,2], Amanda Callaghan[3] and Neil E. Coughlan[1,2]

[1]*Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, 19 Chlorine Gardens, Belfast BT9 5DL, Northern Ireland, UK*

[2]*Queen's Marine Laboratory, Queen's University Belfast, 12-13 The Strand, Portaferry BT22 1PF, Northern Ireland, UK*

[3]*Ecology and Evolutionary Biology, School of Biological Sciences, University of Reading, Harborne Building, Reading RG6 6AS, England, UK*

Author e-mails: *rcuthbert03@qub.ac.uk* **(RNC)**, *ecunningham18@qub.ac.uk* **(EMC)**, *kcrane02@qub.ac.uk* **(KC)**, *j.dick@qub.ac.uk* **(JTAD)**, *a.callaghan@reading.ac.uk* **(AC)**, *neil.coughlan.zoology@gmail.com* **(NEC)**

**Corresponding author*