

Feral swine disease and risk management: Disease entry and exposure

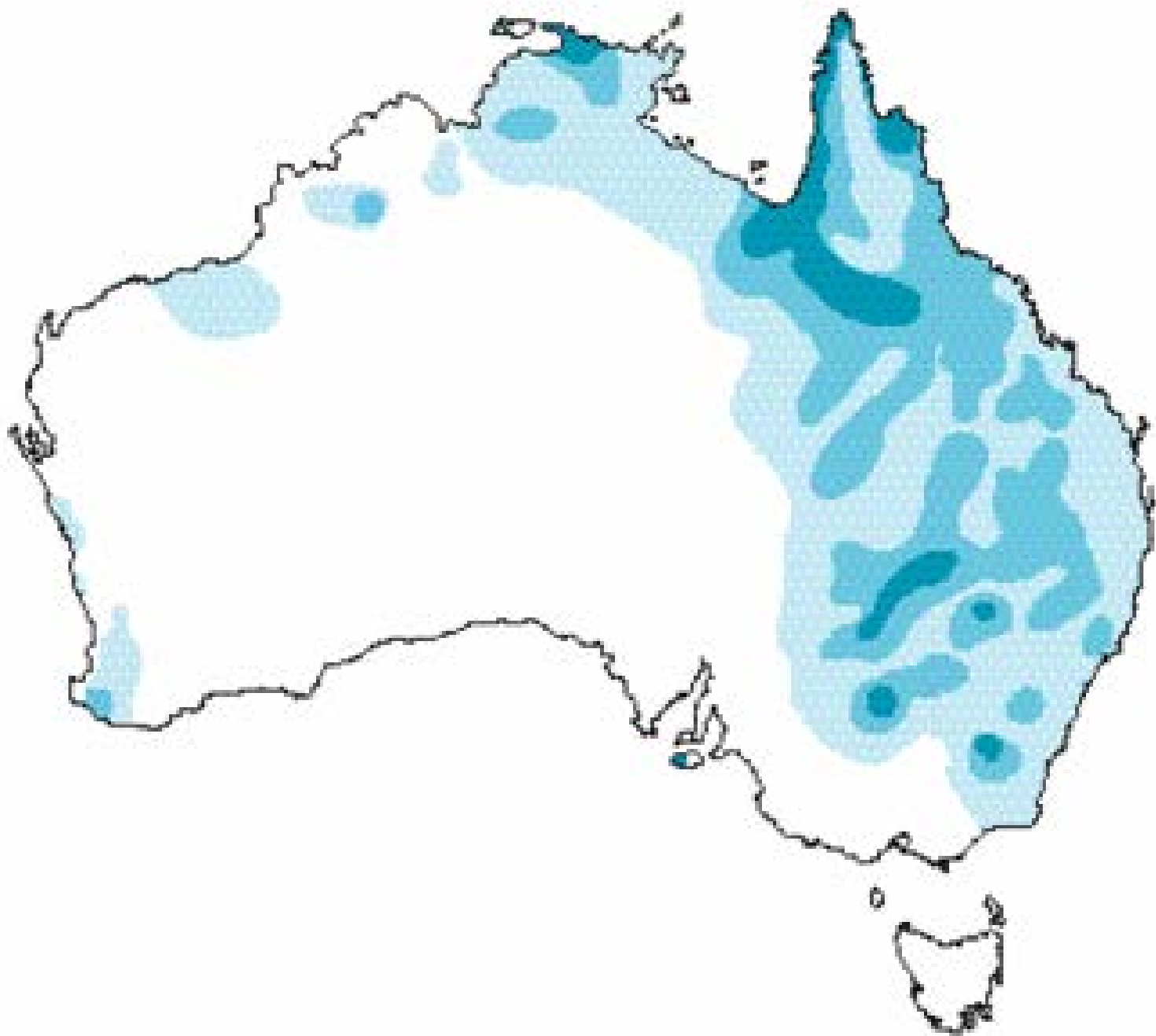
Brendan Cowled
AusVet Animal Health Services



Introduction (2)

1. Introduction to Australian feral swine
2. Habitat modelling and population distribution
3. Disease ecology (including livestock interface)
4. Disease surveillance
5. Panel contributions

Part 1- Australian feral swine



Australian feral swine (2)

- Generally, population control (lethal)
- Reduces density
- Hopefully reduces damage/impact.



Beth Cookson

Australian feral swine (3)

- Control
 - Poison baiting
 - Aerial Shooting
 - Trapping
 - Ground shooting/hunting



Part 2: Habitat modelling and population distribution

Population distribution



- *Sus scrofa* on every continent (except Antarctica)
- National distribution usually known
- Regional distribution can be uncertain (e.g. Australia, USA)
 - Sparsely populated- information scarce
 - Policy makers not in contact with local people
 - Expanding (invasive/introduced)
- Habitat modelling and surveys to address this

Examples- habitat suitability modelling (*Sus scrofa*)

Author	Country	Comment
Medi & Meriggi (2006)	Italy	Hunting bag to predict habitat/population relationship. Mixed woodlands important.
Holland et al. (2007)	UK	Release and establishment of wild boar.
Park & Lee (2007)	Korea	GIS based habitat suitability modelling. Aspect, water and distance from tracks.
Cowled et al. (2009)	Australia	Predict future distribution based on current distribution and suitable features (water, pasture).
Masayuki et al. (2012)	Japan	Range expansion of re-colonising wild boar.
Santilla & Varuzza (2012)	Italy	Hunting bag by environmental variables. Refuges and young forests important.
Segura et al. (2014)	Spain	Predation and environment to predict abundance.
Acevedo et al. 2014	Spain	Large scale distribution by hunting bag for epi.

Habitat suitability modelling (general)



- Explain feral pig presence with regression based approaches (most)
 - Relate an outcome and explanatory variables
 - Outcome = hunter bag, presence or absence of sign, surveys of local people for distribution/density etc.
 - Explanatory variables, land use, landscape features (water, slope, aspect), climate (rainfall, temperature), vegetation etc.
 - Often use information theoretic approaches to select supported models (as predictive, not essential).

Case study- distribution in the Kimberley

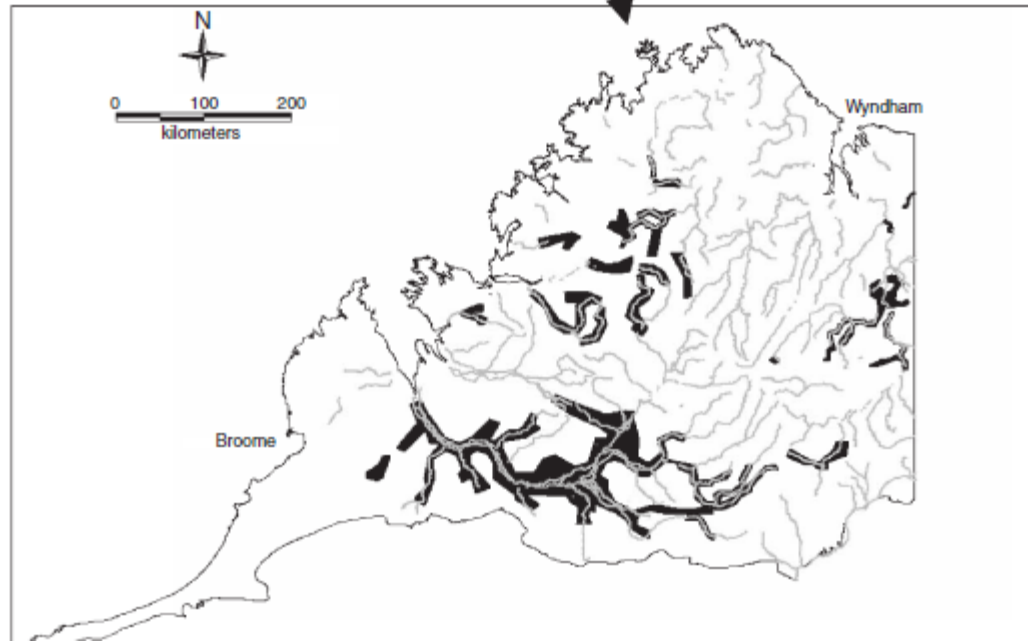
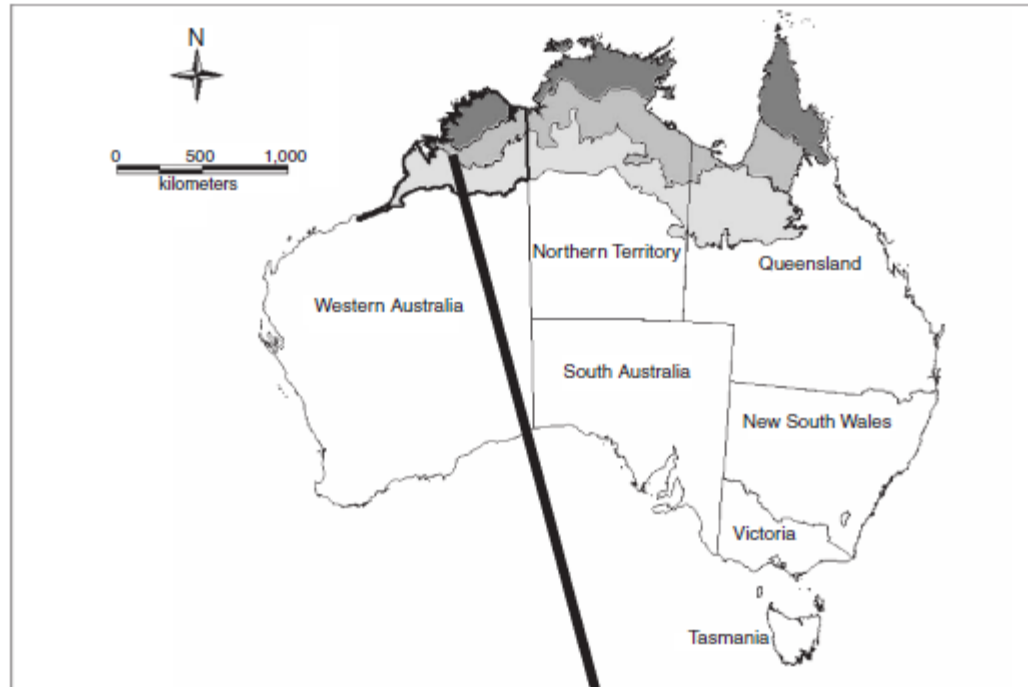
- One example as a case study
- Kimberley
 - remote area of north-west Australia
 - Human population density amongst the lowest in the world
 - Cattle grazing, mining and tourism
 - Moderate density feral swine population~100 years old
- Feral pig distribution uncertain but expanding
- Knowledge of current and future distribution will assist biosecurity planning and modelling

Wildlife Research, 2009, 36, 242–251

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- One exam
- Kimberley
 - remote
 - Human
 - Cattle g
 - Modera
- Feral pig c
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distributions

ⁱB, Sam D. Beckett^C, Andrew Woolnough^D,
me Garner^A

Case study- distribution in the Kimberley (cont.)

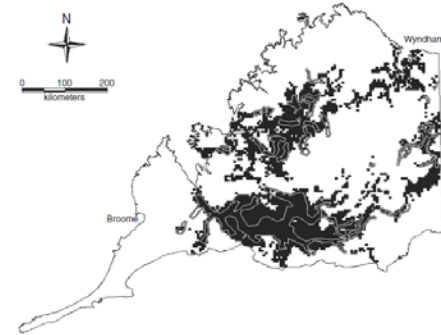
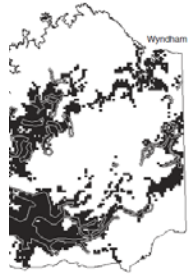
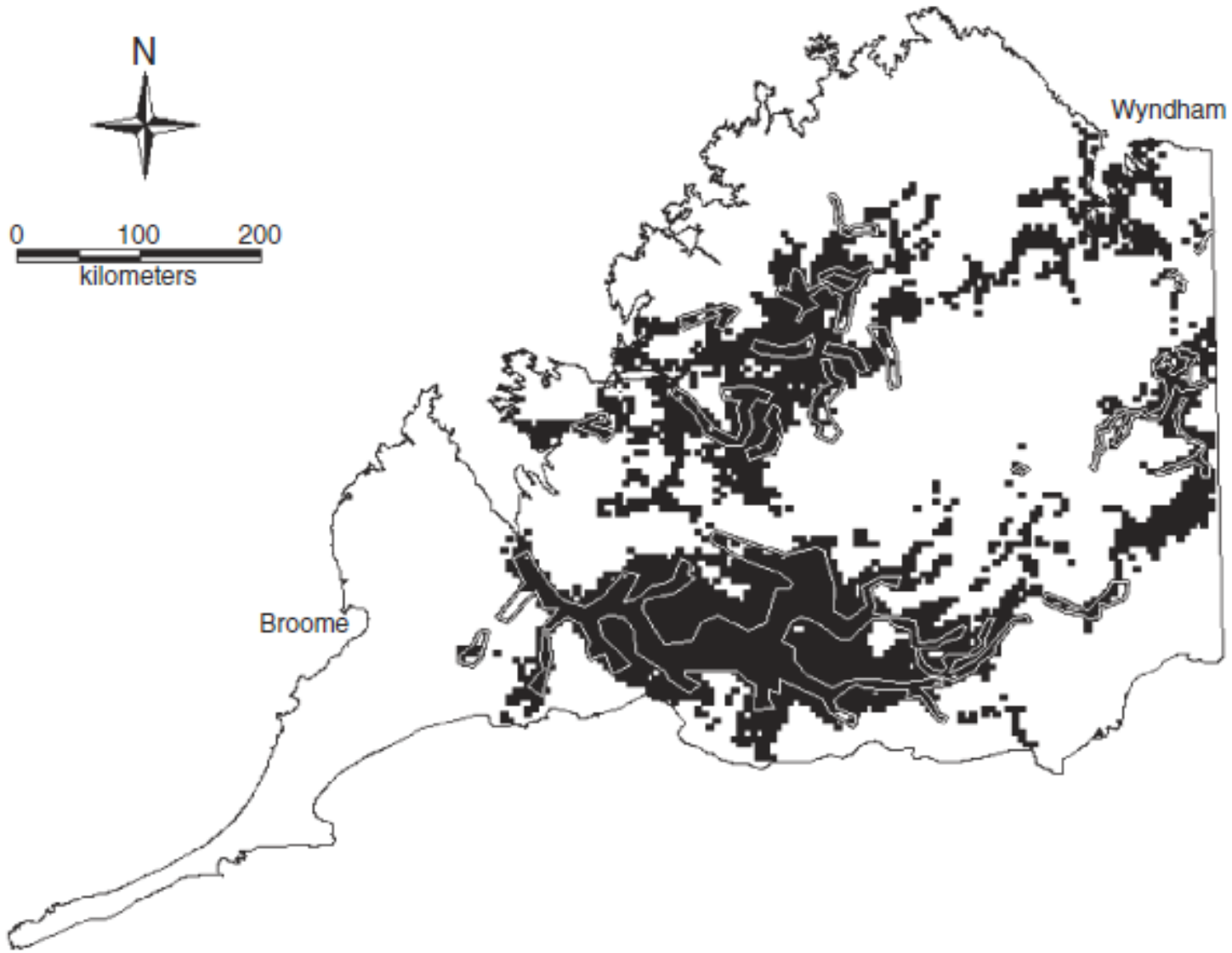


Fig. 4. The simulated distribution of feral pigs through natural dispersal. The black squares show suitable feral pig habitat located within 20 km of known feral pig populations or outside the 20-km range but contiguous with such habitat. The overlaid white lines indicate the known distribution of feral pigs.

- Method
 - Outcome (presence/absence) = questionnaire survey (mapping)
 - Explanatory variables = remote sensed and climate data representing food, water and shelter.
 - Generalised additive models (smoothing function instead of co-efficient)
- Results (Pigs associated with):
 - Flatter, low elevation landscapes
 - lots of surface water
 - high grass growth (seasonal change in NDVI)
 - tree/shrub cover.
- Pigs will probably expand by 62 000 km² in the Kimberley over coming decades though natural dispersal along waterways.

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- Pig dec



gs through natural dispersal. The located within 20 km of known range but contiguous with such known distribution of feral pigs.

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Fig. 4. The simulated distribution of feral pigs through natural dispersal. The black squares show suitable feral pig habitat located within 20 km of known feral pig populations or outside the 20-km range but contiguous with such habitat. The overlaid white lines indicate the known distribution of feral pigs.

Part 3: Disease Ecology



Disease Ecology



- Knowledge required for:
 - Understanding risk/transmission to swine/other species
 - Identifying control or surveillance methods
- Data on Δ incidence over time, space and risk factors will answer most questions (cohort studies)
 - Technically difficult or impossible at scale
 - Too expensive
 - Few comprehensive examples in feral swine (or wildlife generally)
- Therefore
 - Guess/judgement
 - Process modelling
 - Observational (e.g. cross sectional studies (+/- molecular approaches))
 - Other field data collection (ecology data).

Epidemiological (process) modelling

- What?
- Vary depending on treatment of:
 - Chance
 - Space
 - Application perspective
 - Time
 - Structure of the population
 - Method of determining a solution

See Hurd and Kanneene (1993) and Garner and Hamilton (2011) for summaries.

Author	Country	Comments
Ward et al. in press	Australia	FMD in cattle/feral pigs persists due to cattle but can be eradicated.
Dhollander et al. (2014).	Thrace	FMD limited capacity to persist in populations
Stahnke et al. 2013	Germany	Analysis of MOSS, hunting is not sufficient for CSF
Anderson et al. 2013	Spain	Longer term vaccination campaigns of piglets used to eradicate Tb from wild boar reserves.
Zanella et al. 2012	France	Tb transmission reduced if offal removed and red deer depopulated.
Smith 2012	USA	Pseudorabies may not be transmitted by preferential sexual transmission.
Lange et al. 2012	Europe	Vaccination beneficial to control CSF in wild boar.
Cowled et al. 2012	Australia	CSF outbreaks in wild pigs would die out after several years, but much faster with culling.
Wieland et al. 2011	EU	Impact of control measures for ASF
Pineda-Krch et al. 2010	USA	Movement ban may reduce FMD after introduction of FMD to cattle from wild pigs.
S. Kramer-Schadt et al. (2009)	Germany	Drivers of CSFV endemicity in populations
Ward et al. 2009	USA	Discontinuity of feral pigs make predicting FMD outbreaks difficult
Cowled & Garner 2008	Global	Epidemiological models must incorporate certain features.

What factors are important to consider in a feral pig disease model?

- Distribution and habitat connectivity
- Density
- Distribution and density of other susceptible species
- Movements
- Social organisation and group structure
- Age structure
- Climatic or seasonal effects.



Available online at www.sciencedirect.com



Preventive Veterinary Medicine 87 (2008) 197–212

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MEDICINE**

www.elsevier.com/locate/prevetmed

Review

A review of geospatial and ecological factors affecting disease spread in wild pigs: Considerations for models of foot-and-mouth disease spread

Brendan Cowled*, Graeme Garner

Case study: CSF control in Australian feral pigs

- Kimberley (again)
- Modelled the Kimberley population of feral pigs and 'introduced' CSF

Cowled *et al. Veterinary Research* 2012, **43**:3
<http://www.veterinaryresearch.org/content/43/1/3>

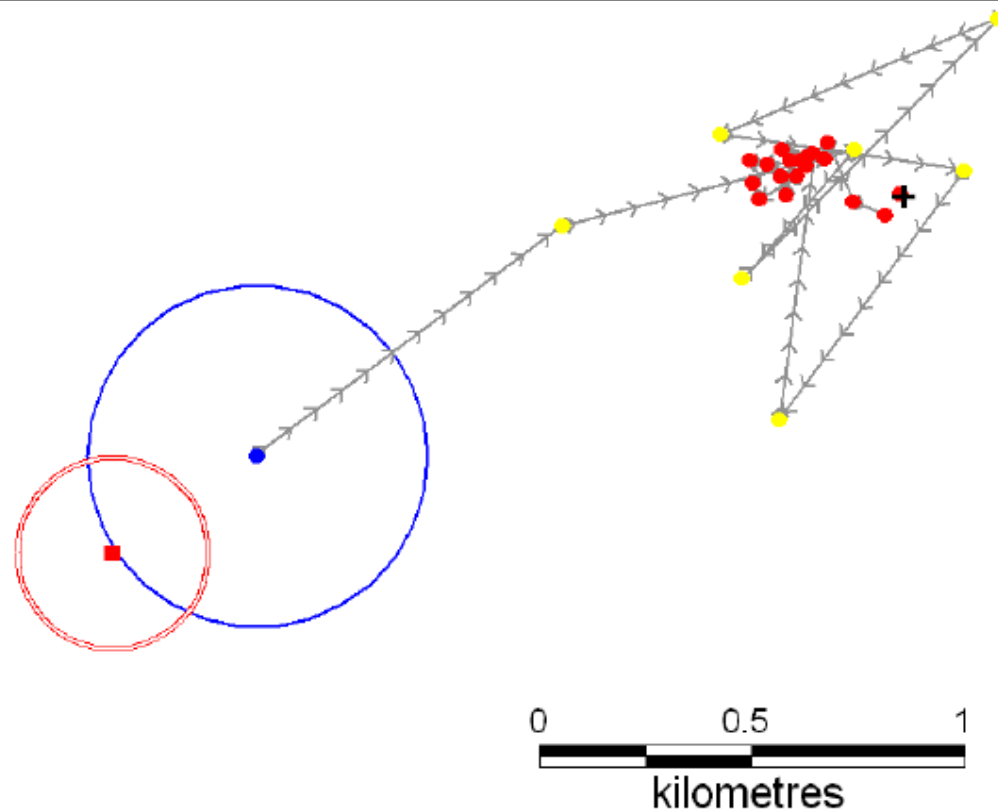


RESEARCH

Open Access

Controlling disease outbreaks in wildlife using limited culling: modelling classical swine fever incursions in wild pigs in Australia

Brendan D Cowled¹, M Graeme Garner², Katherine Negus¹ and Michael P Ward^{1*}



Legend

Herd introducing CSF to susceptible herd

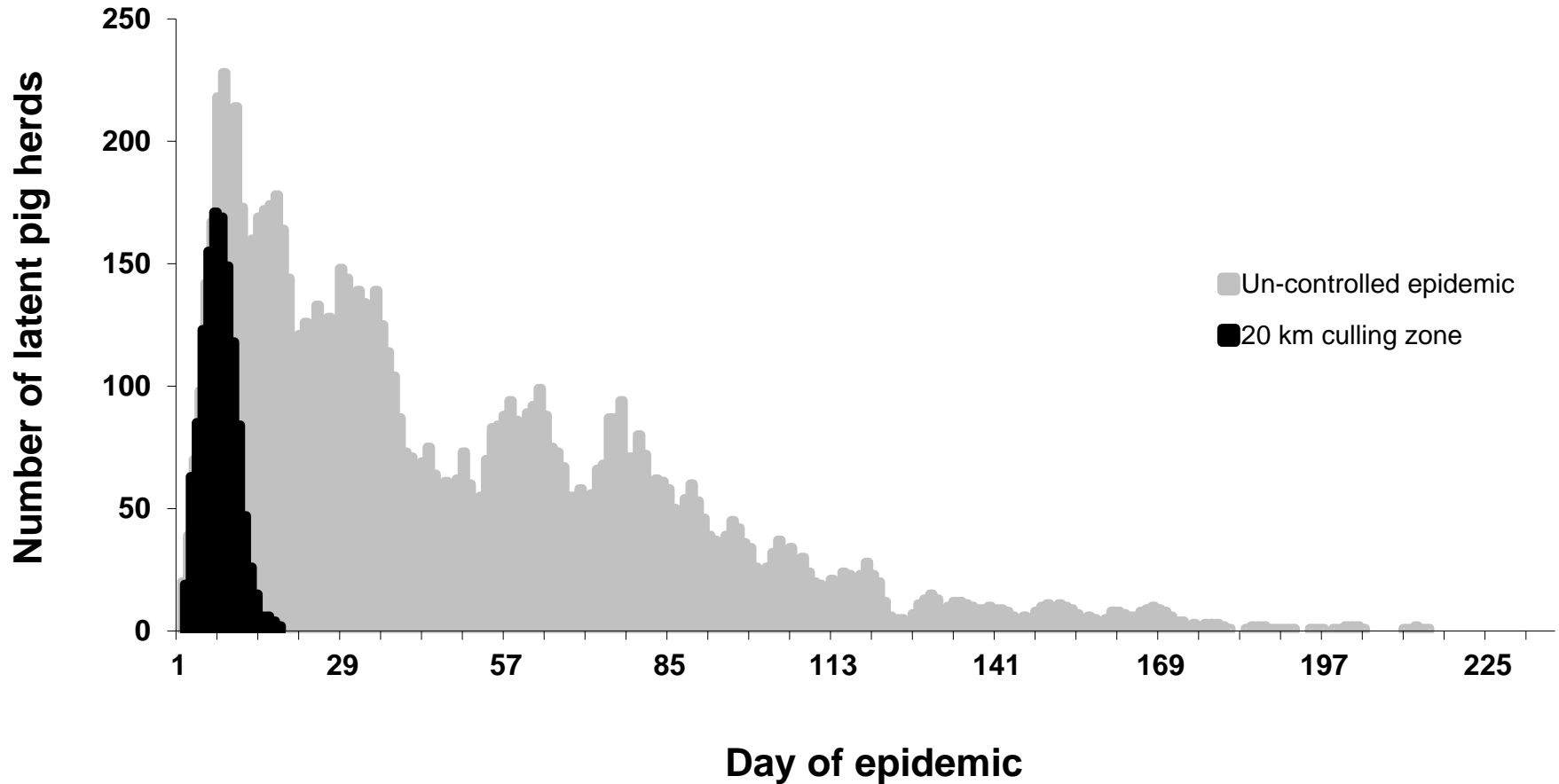
- Infectious herd
- Infectious herd daily home range

Herd receiving CSF from infectious herd

- Susceptible herd
- Susceptible herd daily home range
- Incubating herd
- Clinically affected herd
- + Extirpated herd
- Daily movements of infected herd

Figure 2 Representation of a typical disease transmission event and subsequent daily movements of the newly infected herd in the process model. Explanation: an infected herd (red square) and susceptible herd (blue circle) have overlapping daily home ranges (red and blue circles respectively). Classical Swine Fever transmission may occur according to an arbitrary probability. Following infection the incubating herd continues to move normally for several days (yellow dots) before becoming clinically affected (red dots) with shortened daily movements and eventually having all herd members killed (black cross). This infected herd does not contact another herd and CSF is not transmitted to another

Epidemic curves for controlled and un-controlled CSF in feral pigs



Results Analysis

[<<Back to previous page](#)

4,514 records. TOPIC: (feral pig) OR TOPIC: (feral swine) OR TOPIC: (wild boar) OR TOPIC: (Sus scrofa) AND TOPIC: (disease)

Rank the records by this field:	Set display options:	Sort by:
<ul style="list-style-type: none"> Assignees Authors Concept Codes <li style="background-color: #e0e0e0;">Countries/Territories 	Show the top <input type="text" value="100"/> Results. Minimum record count (threshold): <input type="text" value="2"/>	<input checked="" type="radio"/> Record count <input type="radio"/> Selected field

Analyze

Use the checkboxes below to view the records. You can choose to view those selected records, or you can exclude them (and view the others).

<input checked="" type="checkbox"/> View Records <input type="checkbox"/> Exclude Records	Field: Countries/Territories	Record Count	% of 4514	Bar Chart	Save Analysis Data to File <input checked="" type="radio"/> Data rows displayed in table <input type="radio"/> All data rows (up to 200,000)
<input type="checkbox"/>	USA	564	12.494 %	<div style="width: 12.494%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	GERMANY	368	8.152 %	<div style="width: 8.152%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	SPAIN	311	6.890 %	<div style="width: 6.890%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	JAPAN	236	5.228 %	<div style="width: 5.228%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	ITALY	234	5.184 %	<div style="width: 5.184%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	AUSTRALIA	221	4.896 %	<div style="width: 4.896%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	POLAND	198	4.386 %	<div style="width: 4.386%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	FRANCE	189	4.187 %	<div style="width: 4.187%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	UK	128	2.836 %	<div style="width: 2.836%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	PEOPLES R CHINA	98	2.171 %	<div style="width: 2.171%; height: 10px; background-color: #0056b3;"></div>	
<input type="checkbox"/>	NETHERLANDS	85	1.883 %	<div style="width: 1.883%; height: 10px; background-color: #0056b3;"></div>	

Wildlife disease ecology and disease transmission between wildlife and livestock

A case study using wild pigs



Brendan D Cowled¹, Michael P. Ward¹, Shawn W. Laffan², Francesca Galea³, M.Graeme Garner⁴, Anna MacDonald⁵, Ian Marsh³, Petra Muellner⁶, Katherine Negus¹, Sumaiya.Quasim⁵, Andrew P. Woolnough⁷ Stephen Sarre⁵

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¹The University of Sydney, ²The University of New South Wales, ³Elizabeth Macarthur Agricultural Institute, ⁴Department of Agriculture, Fisheries & Forestry, ⁵University of Canberra, ⁶Epi-interactive, ⁷Victorian Department of Primary Industries



THE UNIVERSITY OF
SYDNEY

Aims

Integrating Survey and Molecular Approaches to Better Understand Wildlife Disease Ecology

Brendan D. Cowled¹, Michael P. Ward^{1*}, Shawn W. Laffan², Francesca Galea³, M. Graeme Garner⁴, Anna J. MacDonald⁵, Ian Marsh³, Petra Muellner⁶, Katherine Negus¹, Sumaiya Quasim⁵, Andrew P. Woolnough⁷, Stephen D. Sarre⁵

1. Understand feral pig disease ecology using *Salmonella* spp.
2. Do feral pigs transmit infection to domestic cattle?





Methods: Sampling

- **Feral pigs:**
 - Search all water features by helicopter
 - All pigs observed humanely destroyed
 - Dead pigs were sampled within 1 hour
 - Faeces and mesenteric lymph nodes (MLN) cultured.
- **Domestic cattle (*Bos indicus*):**
 - A simple random cell selection design
 - Faecal samples collected (no culling!)
 - A helicopter was used and was the most economical and practical means of sampling.





Methods: Salmonella isolation and genotyping

- Cultured all faeces and lymph nodes
- *Salmonella* isolates confirmed by serotyping
- Genotyped using PFGE
- *Salmonella* PFGE DICE similarity coefficient for each pair-wise comparison of *Salmonella*- assume related to transmission.



Methods: Risk factors



- **Feral Pigs**

- Environmental (remote sensing data)
- Demographic
- Population genetic relationships (using microsatellites from pigs)
- Spatial
- Density (aerial surveys of pigs, cattle and wallabies)

- **Cattle**

- Similar but not individual (no culling)

Date	Pig No.	Sex	Colour	Age	Weight (kg)	Head Length (cm)	Body Length (cm)	Head Area (sq cm)	Body Area (sq cm)	Area (sq cm)	Area (sq cm)	Area (sq cm)
1/1/12	101	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	102	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	103	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	104	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	105	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	106	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	107	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	108	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	109	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	110	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	111	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	112	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	113	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	114	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	115	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	116	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	117	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	118	F	B/C	11	5	17	48	104	148	252	272	524
1/1/12	119	M	B/C	11	5	17	48	104	148	252	272	524
1/1/12	120	F	B/C	11	5	17	48	104	148	252	272	524



Hypotheses to explain prevalence or *Salmonella* genetic relatedness

- Density of hosts
- Environmental contamination
- Host immunity
- Resources
- Social interaction



Method: Hypotheses, information theory and molecular epidemiology

Repeated two separate information theoretic analyses for each data set, but using the same hypotheses:

1. Prevalence data

Generalised linear mixed models (logistic)

$$\log\left(\frac{\pi}{1-\pi}\right) = \mathbf{X}_i^T \boldsymbol{\beta} + \text{r. eff. (herd location)}$$

2. Pair-wise genetic data

Linear models with permutation.

$$\textit{Salmonella} \text{ DICE} = \mathbf{X}_i^T \boldsymbol{\beta}$$



Results (descriptive)

- **Cattle (496 samples)**

- Prevalence of Salmonella: 2.2% (95% CI: 1-4%)
- No infected cattle in pig infested areas
- Cattle infected in areas remote from feral pig habitat on artificial bores where cattle densities very high.

- **Pigs (543 samples)**

- Prevalence: 41% (95% CI: 37-45%)
- Hyper-endemic: all ages infected at high prevalence.
- One homogenous genetic pig population
- Lots of diversity in *Salmonella*: median *Salmonella* DICE coefficient 51.85% (Q1: 42.43, Q3: 61.54, range: 10.0-100.0).

Results (information theoretic and pig models)

a. Cross sectional study design (logistic regression models) and prevalence data

Model	Parameters (K)	Bias corrected AIC (AICc)	AICc differences (Δ)	Relative likelihood (evidence ratio)	Probability (Akaike weight)
Resource	10	699.8	0.0	1.0	0.994
Environmental contamination	8	710.9	11.1	251.7	0.004
Density dependant	6	712.1	12.2	455.6	0.002
Host immunity	6	713.6	13.7	964.5	0.001

b. Molecular case series study design (linear regression models) and *Salmonella* genetic data

Model	Parameters (K)	Bias corrected AIC (AICc)	AICc differences (Δ)	Relative likelihood (evidence ratio)	Probability (Akaike weight)
Host immunity	6	339132.1	0.0	0.98	0.580
Resource	11	339132.7	0.6	1.0	0.420
Environmental contamination	8	339218.0	85.9	4.4×10^{18}	0.000
Genetic relatedness model	5	339284.7	152.6	1.4×10^{33}	0.000
Density dependant	7	339735.4	603.3	1.0×10^{131}	0.000

Discussion



- Cattle
 - Feral pigs are not a reservoir or risk factor for *Salmonella* in cattle
- Pigs
 - Ecological resources critical for wildlife influences persistence of *Salmonella*
 - Transmission is influenced heavily by local spatial, social and individual factors
 - Control zones for wildlife disease management should be structured on complex spatial, social, density and resource distribution principals to reduce prevalence as well as transmission
 - Molecular epidemiological approaches and traditional cross sectional surveys are complementary.

NB. *Salmonella enterica* serovar All non-typhoidal salmonella, not host adapted.

Acknowledgements

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Australian Pork Ltd. (1012.361)

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Western Australian Department of Agriculture and Food

Australian Research Council (LP100200110).

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Lyn O'Reilly (PFGE)

Huub Brouwers (Bionumerics)

Peter Fleming (aerial surveys)

Dan Grant (GoGo Station) and Keith Anderson (Jubilee and Quanbun Downs)

We thank the following organisations

University of Sydney Animal Ethics Committee (N00/6-2010/1/5319)

NT Sporting Shooters Association



Disease ecology: Other field data collection

- Ecological data to basic understanding of feral swine
 - Process modelling from first principals
 - risk assessment etc.
- Examples:
 - Molecular ecology
 - Various ecological data collection
 - Home range and movement distances
 - Population distribution/density
 - Effect of control tools.

Part 4: Surveillance (1)

- Free ranging swine difficult
 - Cryptic
 - Hard to handle (usually lethal sampling or chemical restraint)
- Passive surveillance common for disease detection
- Active surveillance usual for research, investigation
- Active surveillance
 - Representative surveillance (rare- population structure uncertain)
 - Risk based surveillance (e.g. Northern Australian Quarantine Service)
 - Convenience (common- e.g. hunter returns) – bias, but inexpensive, practical.



Surveillance (2)

- Some surveillance tools
 - Hunting bag returns
 - Aerial shooting
 - Trapping
 - Meat inspection
 - Faeces (e.g. ASF stable in faeces) (Ferreira et al. 2014)
 - Rope in a bait (FMD secreted orally) (Mouchantant et al. 2014)
 - DNA identification in nymphal ticks (Wodecka et al. 2014)

Part 5: Panelist-Brazil

- Marcello Schiavo Nardi
- Pigs introduced 200 years and 2000 in south
- Been some academic research but national understanding/government involvement since 2012.
- Understanding and knowledge is limited but will increase
- Some baseline data on disease presence



southern states due to commerce



Panelist-ASF (Guinat Claire)

- ASF in caucasus (Georgia) spread to Russia then Europe
- Transmission between free ranging pigs and wild boar (e.g. at water bodies)
- Experimental ASF transmission studies at Pirbright
- Modelling (cluster analysis in pigs around wild boar)
- Passive surveillance (bias and low power)
- Active (only healthy animals- virulence, cost, not representative, dispersal)
- Non-invasive surveillance methods developed
- Maintenance- wild boar unknown, backyard pig producers big role
- Longitudinal studies are occurring



Panelist- Spain (Joaquin Vicente)

- Ad hoc regional research in regions
- University national research on TB, Aujeszky's, Porcine circovirus and Toxoplasma
- Government research:
 - wildlife epidemiological surveillance
 - eradication of TB and ASF
 - Movement restrictions
 - Hunter surveillance (meat inspection) for TB
- Official diseases (Bovine Tb, B suis, Trichinellosis, Aujeszky's Classical swine fever)
 - Active surveillance combined with passive
- Risk factors
 - Density, climate, management (aggregation such as feeding, water etc.), scavenging of hunting remains, complex in multi-host systems (livestock, red deer)
- Transmission to other species- mostly field epidemiology and molecular epidemiology

Session 2 a: Exposure Assessment

9. What information and data are lacking with regard to transmission, spread, and disease ecology in free ranging swine populations globally?

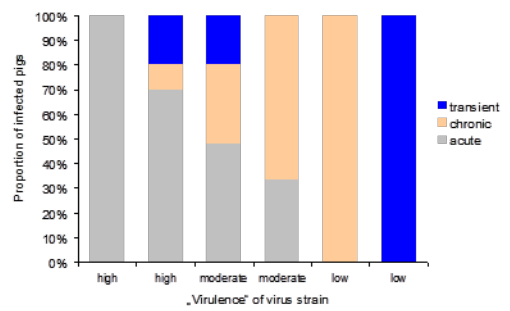
- Comparable estimates of abundance and aggregation
- Behaviour and spatial ecology: ranges and dispersion patterns, response to hunting (perturbation)
- Fine scale interaction between free ranging pigs and other hosts
- Excretion of pathogens and environmental microbiology
- Vectors
- Assessing the role of different spp in whole multihost system
- Comparison between different epidemiological, ecological and management contexts: between countries or continents (islands) comparisons

Panelist- Hans Herman Thulke

- Some good information provided- no time to assimilate completely (in transit!)
- Some references for the earlier tables
- Hunter verse indicator boar for detection
- A good slide on drivers for persistence of CSF

Drivers of persistence of CSFV in free-ranging wild boar populations (ecological model)

Variability
(Variance in infectious period)



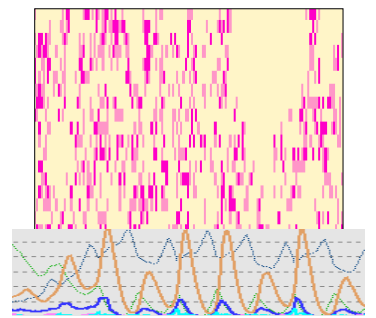
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MaxLethalTime

% Transient

Acute/Chronic

Size / Density



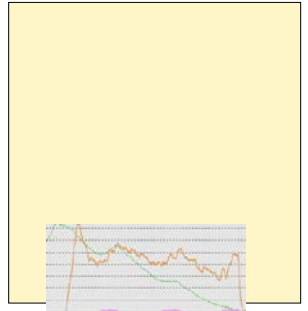
Population numbers
(Density * Area)

Inf-Between-Herds

Mean Infectious period
(Virus characteristics)

Transmission
(Virus characteristics)

Inf-In-Herd



Ro*

0

Conclusions (1)

- Disease ecology (+ interspecies transmission) is a very complex area:
 - Substantial amount of research, but *ad hoc*
 - Context specific (ecosystem, agricultural and social system, species/subspecies, organism and resources)
 - Cross sectional surveys and process modelling mostly- not the best evidence
 - Molecular epidemiology showing great promise when combined with good study design (e.g. cross sectional surveys)
 - Requires a substantial systematic literature review to draw it together.....? USDA?? From this meeting??

Conclusions (2)

- Surveillance
 - passive will always be important to detect
 - Active surveillance
 - Hunter is common and inexpensive
 - Where pigs invasive, then lethal sampling such as aerial shooting.
 - Lots of good epidemiological strategies (freedom testing, risk based sampling, scenario tree modelling)
 - Context specific!

The end

