Bayesian spatial regression modelling of loggerhead sea turtle bycatch in the Pacific pelagic longline fisheries

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Milani Chaloupka

Ecological Modelling Services P/L
PO Box 6150, Univ Queensland, St Lucia, Queensland, Australia
Background …

- Loggerhead, an endangered marine species exposed to fisheries hazards in the Pacific.
- 2 distinct Pacific genetic stocks - a Japanese stock and an east Australian stock.
- Both stocks have shown significant declines over the past few decades due mainly to egg harvesting, habitat destruction, and incidental capture in coastal and pelagic fisheries.
- Both stocks showing recent signs of recovery.
Previous studies …

- Lewison et al. (2004) tried to quantify the effects of longline fisheries on Pacific loggerheads
- seriously flawed because of —
  - inadequate fisheries bycatch data
  - incomplete fisheries effort data
  - inappropriate use of catch-effort ratio estimators
  - invalid loggerhead demographic assumptions
  - invalid estimates of post-hooking sea turtle mortality
  - inadequate modelling approach (linear covariate functional form, uncorrelated spatial variation, failed to account for sampling and structural zeroes in bycatch count data)
Pacific loggerheads (pelagic or oceanic phase)

<table>
<thead>
<tr>
<th></th>
<th>Chaloupka, Limpus</th>
<th>Lewison (rmi corrected)</th>
<th>Lewison (rmi &amp; nesters corrected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>number vulnerable to longline gear</td>
<td>Tv</td>
<td>1,242,971</td>
<td>133,333</td>
</tr>
<tr>
<td>proportion vulnerable to longline gear</td>
<td>V</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>total population</td>
<td>T</td>
<td>1,775,673</td>
<td>333,333</td>
</tr>
<tr>
<td>number nesting age females</td>
<td>Nf</td>
<td>6,000</td>
<td>3,000</td>
</tr>
<tr>
<td>number nesting age females (pa)</td>
<td>Nfpa</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>proportion nesting age females</td>
<td>Pnf</td>
<td>0.00545</td>
<td>0.018</td>
</tr>
<tr>
<td>female remigration interval (years)</td>
<td>rmi</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>sex ratio</td>
<td>sr</td>
<td>0.62</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Lewison et al have underestimated the number vulnerable (Tv) by > 19 times !!!!!!
New approach …

- accounts for over-dispersed and/or zero-inflated response data, nonlinear covariate functional form, time-varying effects and georeferenced spatial effects
- fully Bayesian inference framework using MCMC simulation techniques
- spatial effect derived using 2D smoothing spline surface then AKIMA bicubic spline interpolation for irregular spaced data for imaging plotting
Loggerhead sea turtle life cycle

- Eggs
  - Temperature-dependent hatching & sex determination
  - Nest predation, nest washover, beach erosion, harvesting

- Hatchlings
  - Neonates
  - Pelagic immatures
  - Benthic immatures
  - Pelagic juveniles
  - Benthic subadults
  - Potential adult breeders

- Breeding migration
- Post-breeder

- Vitellogenesis
  - Environmental stochasticity

- Temperature-dependent hatching & sex determination

- Coefficient of harvest mortality
  - Coastal trawl fisheries
  - Pelagic longline fisheries

- Breeding
  - Migration
  - Nest predation, nest washover, beach erosion, harvesting
somatic growth behaviour

(a) Size growth (cm CCL) over age (years since benthic recruitement)
(b) Growth rate (cm CCL) over age (years since benthic recruitement)

first breeding event
pacific nesting population trends
foraging ground-specific breeding probabilities (west Pacific loggerhead stock)
Modelling post-release mortality of loggerhead sea turtles exposed to the Hawaii-based pelagic longline fishery

Milani Chaloupka¹*, Denise Parker², George Balazs³

¹Ecological Modelling Services Pty Ltd, PO Box 6150, University of Queensland, St Lucia, Queensland 4067, Australia
²Joint Institute for Marine and Atmospheric Research, 8604 La Jolla Shores Drive, La Jolla, California 92037-0271, USA
³National Marine Fisheries Service, Pacific Islands Fisheries Science Center, 2570 Dole Street, Honolulu, Hawaii 96822-2396, USA

ABSTRACT: Loggerhead sea turtles Caretta caretta are an endangered species exposed to anthropogenic hazards such as pelagic longline fisheries. Many loggerheads caught in these fisheries are alive when released from the gear, but many probably die soon after because of hook injuries or line entanglement. Robust estimates of post-release mortality are essential for stock assessment and evaluating the benefit of releasing turtles caught alive in the gear, yet none are available for any sea turtle species. Here, the post-release mortality of 40 loggerheads caught in the Hawaii-based pelagic longline fishery was investigated using satellite telemetry deployed by a National Marine Fisheries Service (NMFS) observer program. We modelled time-to-failure of all transmitters using nonparametric statistical modelling (Kaplan-Meier-Turnbull, local regression) to derive survival and hazard functions for light and deep hooked loggerheads. There was a significant difference between the survival functions for light and deep hooked loggerheads within 90 d of release, but no difference between survival functions after this time. But satellite transmitters fail for many reasons (defects, battery failure, transmitter detachment, turtle death), which results in a hazard function that confounds these competing risks. Hence we propose that it might not be possible to infer true post-release mortality based on satellite telemetry unless the cause of each transmitter failure is known, which is rarely the case. We discuss other survey design and statistical modelling challenges involved in the evaluation of post-release mortality based on satellite telemetry.

KEY WORDS: Loggerhead sea turtles · Pelagic longline fisheries · Satellite telemetry · Post-release mortality · Failure time modelling · Competing risks
An example …

- SPC fisheries catch-effort data for 2004
- response var = swordfish catch
- explicit modelling of cpue (Bayesian spatial GAMM)
- swordfish from shallow-set pelagic longliners
- loggerheads at most risk to shallow-set fisheries
- so swordfish catch-effort data may be a useful proxy for loggerhead bycatch when no data available
- model will eventually include loggerhead bycatch