**Patterns and rates of limb Loss in a snow crab (*Chionoecetes opilio*) population in Eastern Canada**

Tobie Surette and Mikio Moriyasu

**Nomenclature: (patterns | incidence | rates) of (limb | pere(i)opod | leg | cheliped) (autotomy | loss)**

**Keywords: Autotomy, snow crab, limb loss**

**DATA DESCRIPTION**

* Missing leg data were not recorded below certain size thresholds, which varied from year to year, but all crab with 60 mm CW had their missing leg pattern recorded.
* All snow crab were measured for carapace width, along with the condition of the carapace.
* Missing legs were noted for all sizes above 50 millimeters, though they were measured for smaller-sized crab in some years.
* Missing leg codes ranged from 1 to 7, with 1 indicating an missing legs (autotomy) and 2 indicating a regenerating leg. Codes 3, 4, and 5 indicated increasing degrees of disease marks, and code 6 indicated an unknown virus mark.
* Code 7 indicates … ?

**Summary:**

Crustaceans may lose their pereiopods (i.e. walking legs or chelipeds) due to predation, competition or handling during fishing. Missing pereiopod patterns were analyzed using survey data from a population of snow crab (*Chionoecetes opilio*) in the southern Gulf of Saint Lawrence. Pereiopod loss rates displayed significant variation by sex, maturity stage and size of the animal, as well as the condition of its carapace. Temporal trends and spatial patterns were also evident.

Large differences were found between the sexes. Whereas rates for immature male crab were generally low and constant over all sizes, they were found to be two to three times higher in sexually mature versus immature male crab. This pattern is even apparent in newly moulted crab, with crab which had moulted in previous years showing only a moderate increase in pereiopod loss. In addition, the loss rates were twice as high in smaller mature males than for larger ones. Such results strongly hint at mating

competition as the main mechanism for pereiopod loss.

Pereiopod loss rates in females were about 60% those observed in males. Mature females similarly showed higher rates than immature ones, with newly moulted females having a moderate increase in pereiopod rates than older mature females. This may be a function of the longer life expectancy of mature female versus male snow crab. Rates for females showed little variation with size.

In males the 2nd pereiopods had the highest loss rates whereas the chelipeds and 5th pereiopods had the lowest. In females, the 2nd and 5th pereiopods had the highest rates whereas the chelipeds had a rate less than half that of any other pereiopod.

Annual changes in the pereiopod rates show some correlation with underlying population dynamics, most notably high abundance levels in large males. Results suggest that intra-specific competition between crab may be the main drivers in the patterns observed.

**Methodology:**

Annual snow crab trawl surveys have been conducted in the southern Gulf of Saint Lawrence since 1988. While the spatial extent sampled by the survey has expanded over its 30-odd year history, from its beginning the survey was designed to cover most of the snow crab’s prime habitat in the southern Gulf. The survey was later expanded into more marginal habitat: in shallow warmer coastal areas, and in deeper warmer waters along the Laurentian Channel to the northeast.

The biological data set is quite large, at about 30000 crabs measured annually. These are sexed and measured to determine size, sexual maturity, the condition of the carapace and the pattern of missing pereiopods.

Crab size is assessed by measuring the carapace width (CW) using a pair of modified Vernier calipers. Male snow crab range in size up to 140mm CW, and females up to 95mm CW.

Missing leg pattern was assessed by noting the presence or absence for each of the snow crab’s 10 pereiopods. Regenerating limbs were similarly noted. For some years, the missing leg pattern for crab smaller than 40 mm CW was not noted. Only limbs Only legs which were lost naturally and not through survey fishing operations were considered in the following analyses.

**Factors related to pereiopod loss:**

Latent (unobserved)

* Moulting
* Predation
* Competition
* Mating
* Fishing (through by-catch). (Only males larger than about 90mm CW would be affected by the fishery, though it may have indirect effects)

Observed:

* Sexual (i.e. morphometric) maturity (competition and mating)
* Index of time elapsed since last moult (i.e. carapace condition).
* Parity (crab side)
* Crab size (carapace width (mm)
* Year (encompasses all of the latent factors which vary through time).
* Location (encompasses all of the latent factors which vary through space).

**Statistical model:**

* Missing limbs were treated as 10-element binary variables for each crab.
* Probabilities were modelled using a logit-linear formulation of fixed and Gaussian random effects.
* The fixed-effects considered were an intercept term, modelling the global probability; the leg-position, indicating the cheliped and 1st to 4th walking legs; the parity or which side of the crab for the corresponding limb; the shell condition of the crab; the maturity stage of the crab; and the size of the crab.
* Random effects were annual year effects and their interaction terms with leg position,
* A Gaussian process with Matern covariance was defined over the study area was used to model spatial variation in missing leg probabilities.

* A final consideration was given to model whether the presence of one missing limb was correlated with the loss another limb in each crab.
  + For example, the loss of a cheliped may render the crab more vulnerable to losing further limbs.
  + The loss of both chelipeds may lead to mortality or indicate conflict avoidance in males.
* Separate analyses were made for each sex.

Maximum likelihood solutions and inference of random effects were obtained using Template Model Builder (Kristensen et al. 2016).

**Data issues:**

* For some years, missing limbs were not noted below 60mm CW rather than 40mm CW as was generally the case.
* Insert table of survey summaries by year, which include the number of samples by sex by year, a brief survey description, redesigns, etc...

**Results**

**Univariate marginal effects, show limb loss by:**

* Crab size
* Sexual maturity
* Leg position
* Parity
* Survey year
* Region

**Bivariate marginal effects:**

* Crab size versus leg position
* Leg position versus survey year
* Leg positions versus size.
* Parity versus maturity stage.
* Survey year
* Region

**Discussion**

What are the types of **effects** that we can expect with limb loss? With cheliped loss?

* Increased disease or parasite infection rates.
* Increased mortality.
* Change in moult probability(?)
* Specific to cheliped loss, we may expect:
  + A possible reduction of reproductive success.
  + Decreased ability to feed (decrease in condition).
  + Decreased ability to fend off predators or competitors, i.e. increased limb loss and/or mortality.

**Publication Summaries**

**Fonseca et al. 2008** (longevity, dactyl wear).

Species: Snow crab (*Chionoecetes opilio*) .

Location: northern gulf St. Lawrence, QC, Canada.

Based on mark-recapture data, time-at-liberty observations are related to shell condition observations to reconstruct time-since-terminal-moult for adult male snow crab.

A linear relationship between the total number of missing pereopods and time-since-moult is also constructed. The linear model is n = 0.09x + 0.46, where x is the number of years since terminal moult. This model predicts that the number of missing pereopods almost doubles from 0.46 at the moult to maturity, to 0.92 at year 5.

Table 3: Percentage of adult male snow crab from Saguenay Fjord missing 0, 1, 2, or 3-6 pereopods, by shell condition stage (SC1 to SC5).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **# missing** | **SC1** | **SC2** | **SC3** | **SC4** | **SC5** |
| 0 | 71.2 | 69.4 | 52.7 | 48.2 | 36.3 |
| 1 | 15.9 | 19.6 | 27.7 | 28.8 | 30.0 |
| 2 | 8.3 | 7.0 | 12.3 | 14.4 | 21.7 |
| 3-6 | 4.6 | 4.0 | 7.3 | 8.6 | 12.0 |
| # obs | 131 | 1650 | 2983 | 2379 | 601 |

**Dvoretsky** et al. **2009 (**Limb autotomy patterns)

Species: Red king crab (***Paralithodes camtschaticus)***

Location: Coastal Barents Sea.

* Diving and trap study (a few hundred individuals at three sites).
* *A limb stump that was either scarred, or possessed a papilla or limb bud, was classified as a missing limb*.
* Parity differences between left and right (more missing limbs on the right side, notably cheliped)
* Differences between males and females
* Mature individuals have high rates than immature ones (about 2x).
* Small sample size makes interregional and size-based comparisons unreliable.
* *In the Barents Sea, P. camtschaticus is predated by Atlantic cod, Gadus morhua, wolffishes Anarhichas spp. and various seals (Kuzmin and Gudimova, 2002; Sokolov and Milyutin, 2008).*

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library(gulf.data)

library(gulf.graphics)

library(TMB)

clm()

clg()

# Read snow crab survey biological data:

b <- read.scsbio(1988:2021)

b$year <- year(b)

b$maturity <- is.mature(b)

b <- b[which((b$carapace.width > 0) & (b$carapace.width <= 150)), ]

b <- b[which(b$carapace.width >= 50 & b$sex == 1), ]

# Format durometer readings:

b$durometer <- gsub("[\*]", "", b$durometer)

b$durometer <- as.numeric(b$durometer)

b$durometer[which((b$durometer <= 0) & (b$durometer > 100))] <- NA

# Fix missing legs:

b$missing.legs[b$missing.legs == "\*\*\*\*\*\*\*\*\*"] <- "\*\*\*\*\*\*\*\*\*\*"

# Define variables:

years <- sort(unique(b$year))

# Define missing leg patterns:

m <- matrix(0, ncol = 10, nrow = nrow(b))

for (i in 1:10) m[, i] <- as.numeric(substr(b$missing.legs, i, i))

m[is.na(m)] <- 0

# Compile and load TMB program:

clc(); compile("test.cpp")

dyn.load(dynlib("test"))

# Define data:

ix <- sort(sample(1:nrow(m), 20000))

data = list(z = m)

# Define initial parameters:

parameters <- list(leg\_effect = rep(0, ncol(m)), # Leg effect parameters.

log\_sigma\_leg = -1, # Leg effect error parameter.

L\_eps = rep(0, 0.5 \* ncol(m) \* (ncol(m)-1)),

log\_scale\_eps = rep(0, ncol(m)),

log\_sigma\_L\_eps = -1,

log\_sigma\_scale\_eps = -1)

# Initialize TMB object:

obj <- MakeADFun(data = data,

parameters = parameters,

random = c("leg\_effect", "L\_eps", "log\_scale\_eps"),

DLL = "test")

# Fit model:

theta <- optim(obj$par, obj$fn, obj$gr, control = list(maxit = 500, trace = 3))

rep <- sdreport(obj)

fixed <- summary(rep, "fixed")

random <- summary(rep, "random")

# Compile rates of missing legs by size and year:

res <- matrix(NA, nrow = 150, ncol = length(years))

rownames(res) <- 1:150

colnames(res) <- years

for (i in 1:length(years)){

ix <- which(b$maturity & (b$year == years[i]))

r <- (m[ix,j] == 1) | (m[ix,j+5] == 1)

r <- apply(m[ix, ] == 1, 1, function(x) sum(x) / 10)

tmp <- aggregate(r, by = list(cw = round(b$carapace.width[ix])), mean)

res[as.character(tmp$cw), as.character(years[i])] <- tmp$x

}

res[, "1996"] <- NA

# Plot rates:

image(1:150, years, res, xlab = "", ylab = "", col = colorRampPalette(c("white", "black"))(10),

zlim = c(0, 0.15), xlim = c(60, 120))

mtext("Carapace width (mm)", 1, 2.5, cex = 1.5)

mtext("Year", 2, 2.5, cex = 1.5)

box()

logit <- function(x) log(x/(1-x))

# Plot rate anomalies:

cols <- c(rev(colorRampPalette(c("white", "red"))(10)[-1]), "white", colorRampPalette(c("white", "black"))(10)[-1])

image(1:150, years, logit(res) + 2.6, xlab = "", ylab = "",

col = cols,

breaks = seq(-1, 1, len = length(cols)+1),

xlim = c(60, 110))

mtext("Carapace width (mm)", 1, 2.5, cex = 1.5)

mtext("Year", 2, 2.5, cex = 1.5)

box()