UNIVERSITY of TASMANIA

IMAS

Institute for Marine and Antarctic Studies

Estimating moult timing in lobsters – A Bayesian Approach

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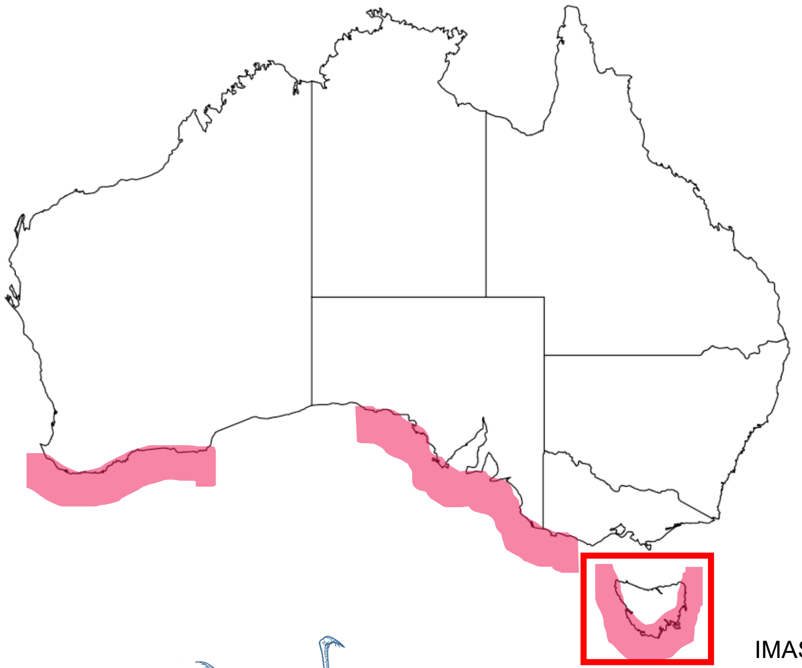
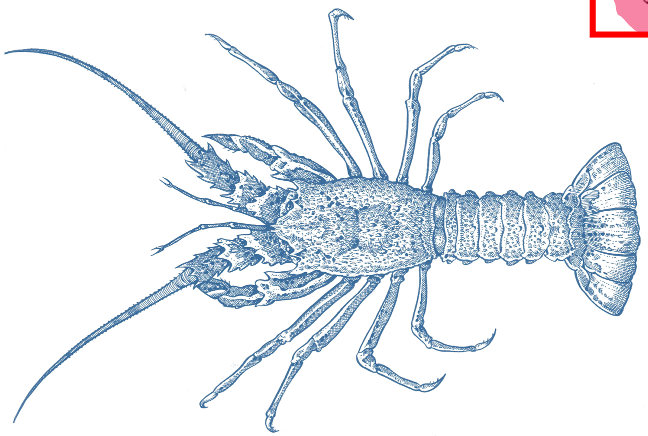
Wednesday 4th September – AASC 2024

Introduction

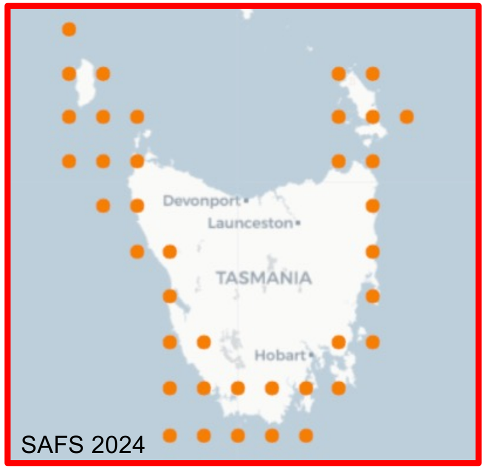
- Southern Rock Lobster (SRL) is a highly valuable living marine resource
- In the Tasmanian Rock Lobster Fishery ~1000 tonnes are harvested annually
- Spatial / environmental variation in growth and biology



IMAS 2023

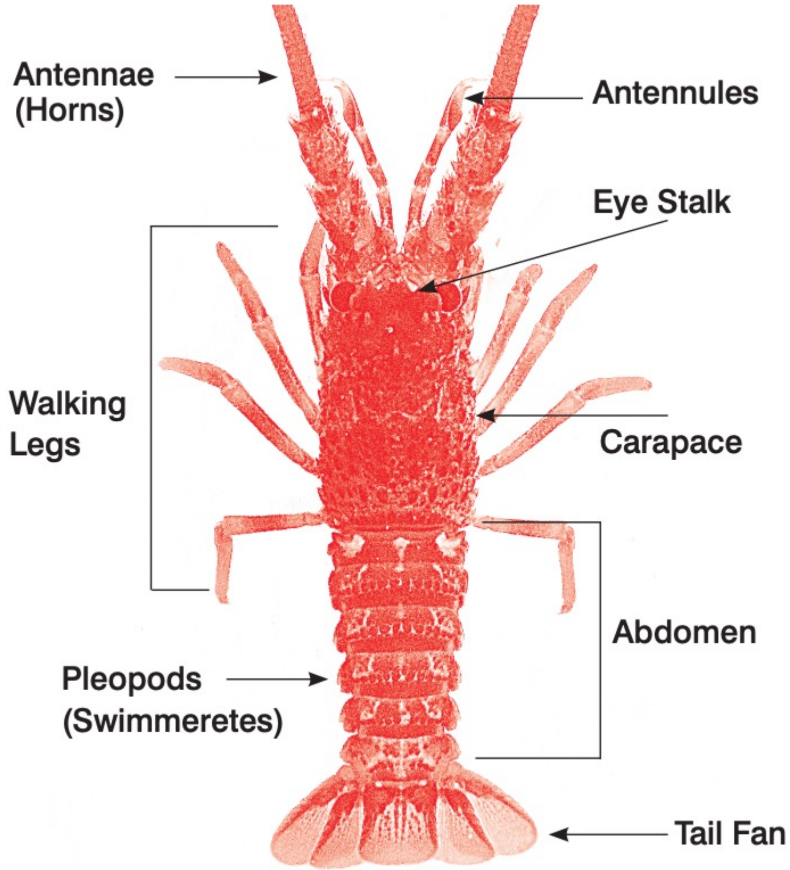


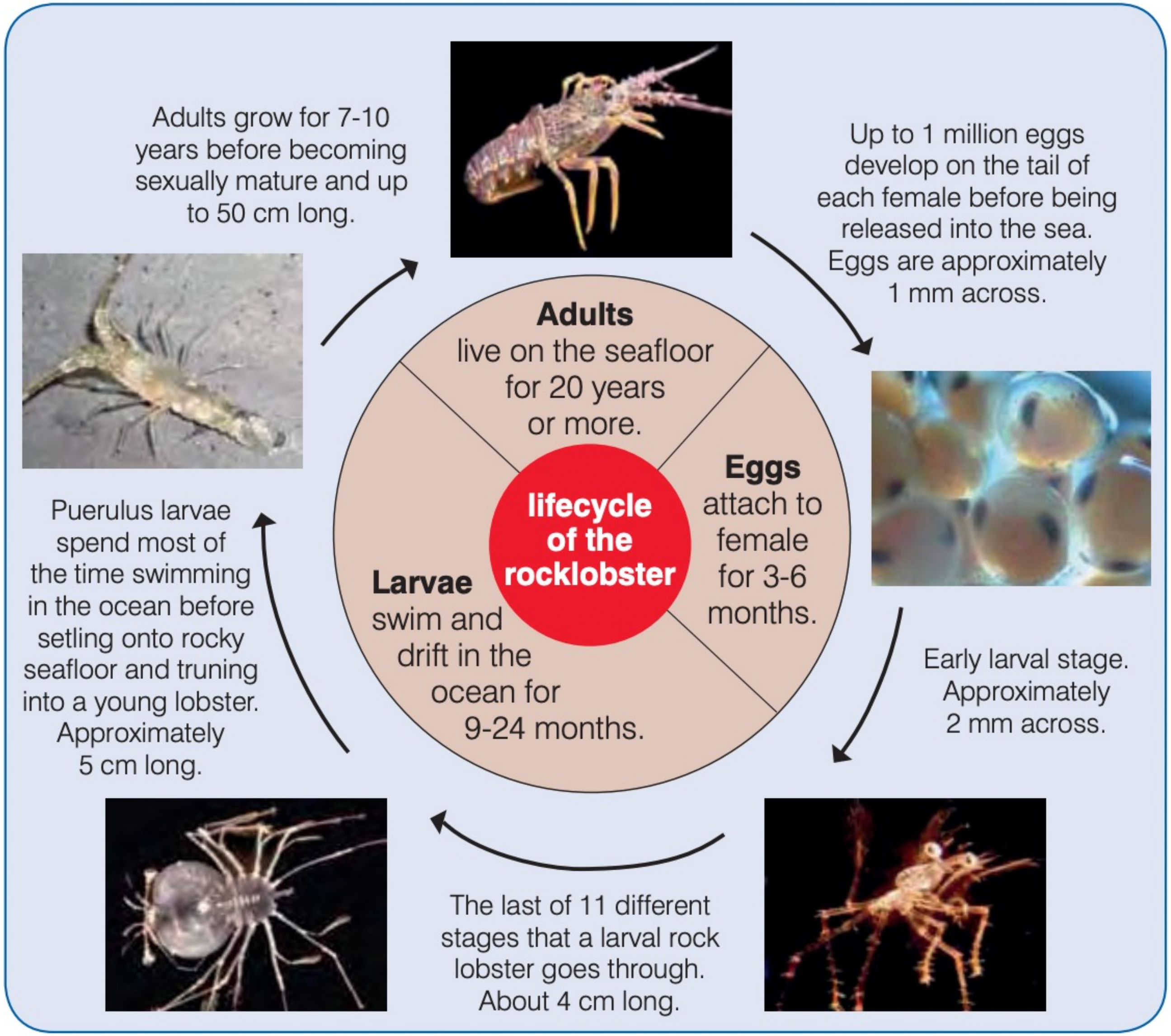
GoodFish 2023



SAFS 2024

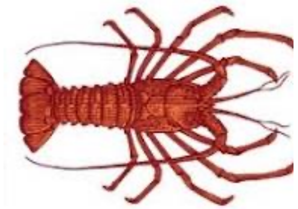
Brief Biology Summary

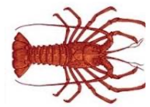


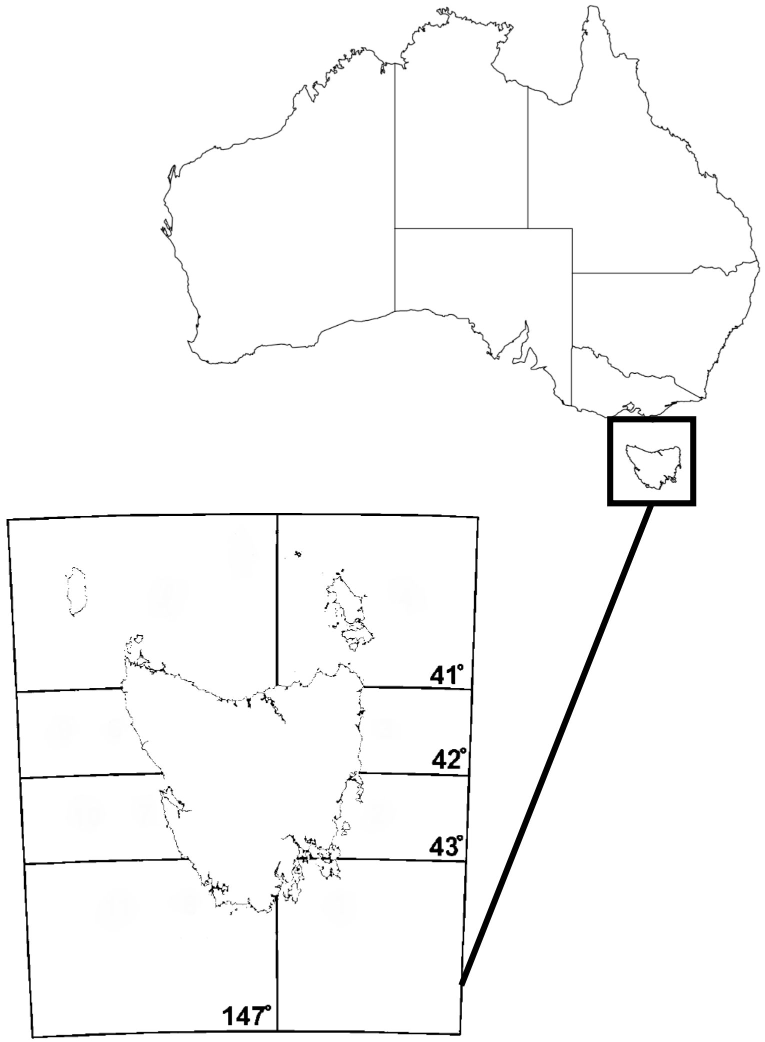


Background (When to Harvest)

- **Southern Rock Lobster** (SRL) live export of a high-grade product
- Quota managed fishery → license to take a certain amount
- They shed their shell to grow (moulting)
- Newly moulted + Live export = increased mortality
- Seasonal fishing closures should coincide to mitigate this risk
- <u>**Commercial capture-tag release data**</u>







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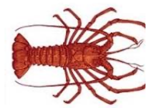
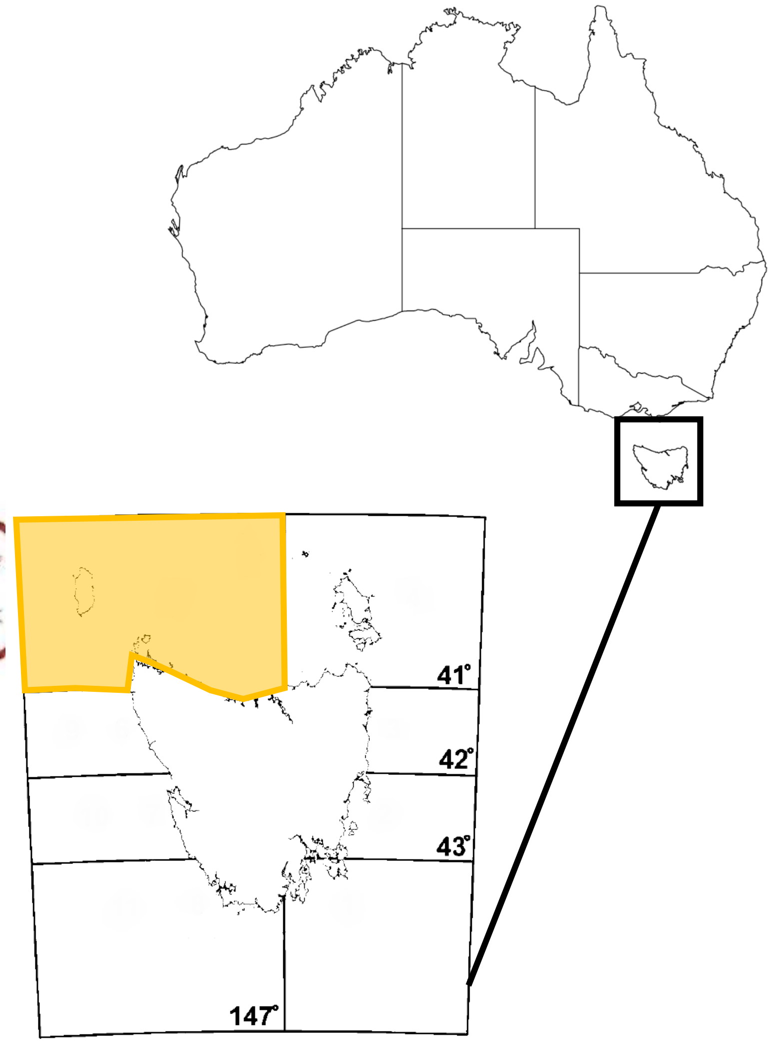
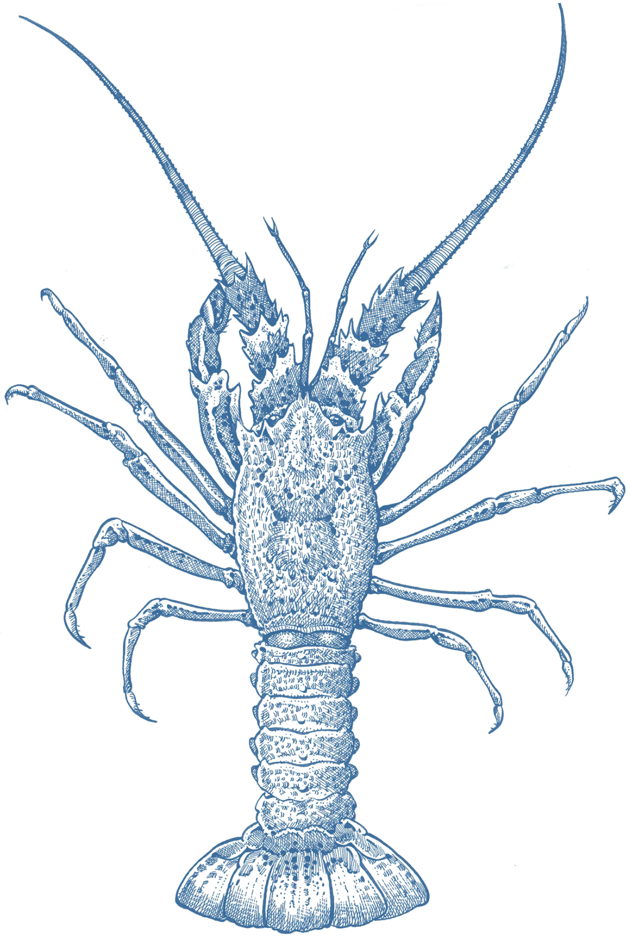






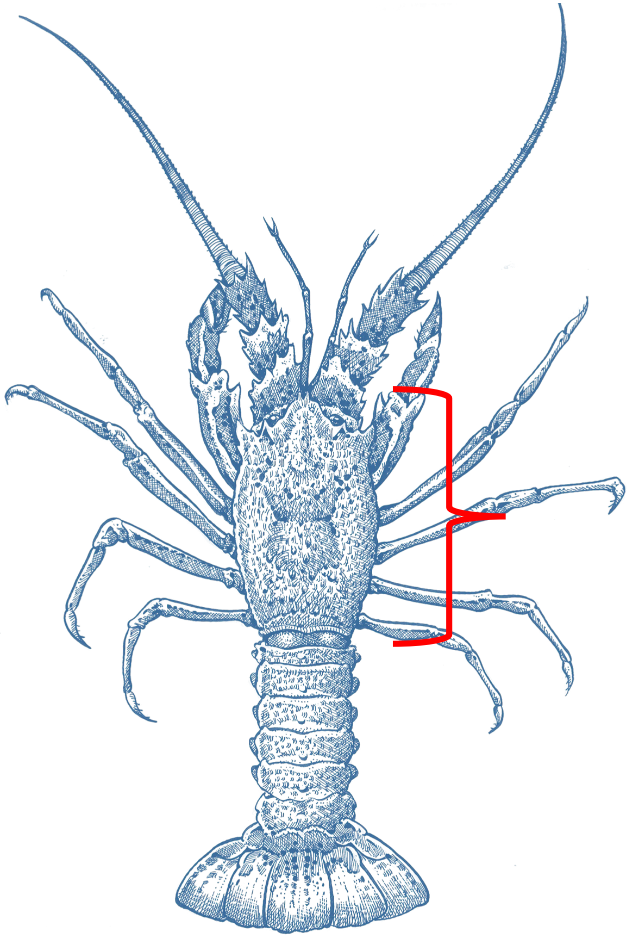
Situation & Plan (When to Harvest)

Moulting

- Females: April to June
- Males: August to September

Indications of moulting

- Size change (carapace length)
- Evidence of limb regeneration
- Evidence of pleopod regeneration
- Evidence of sexual maturity change (female)



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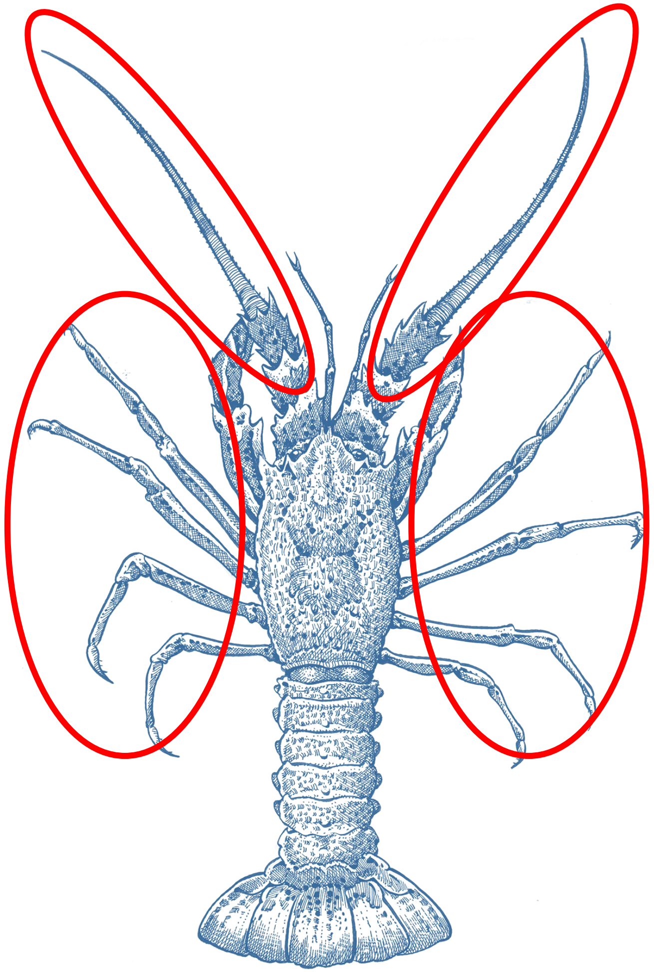

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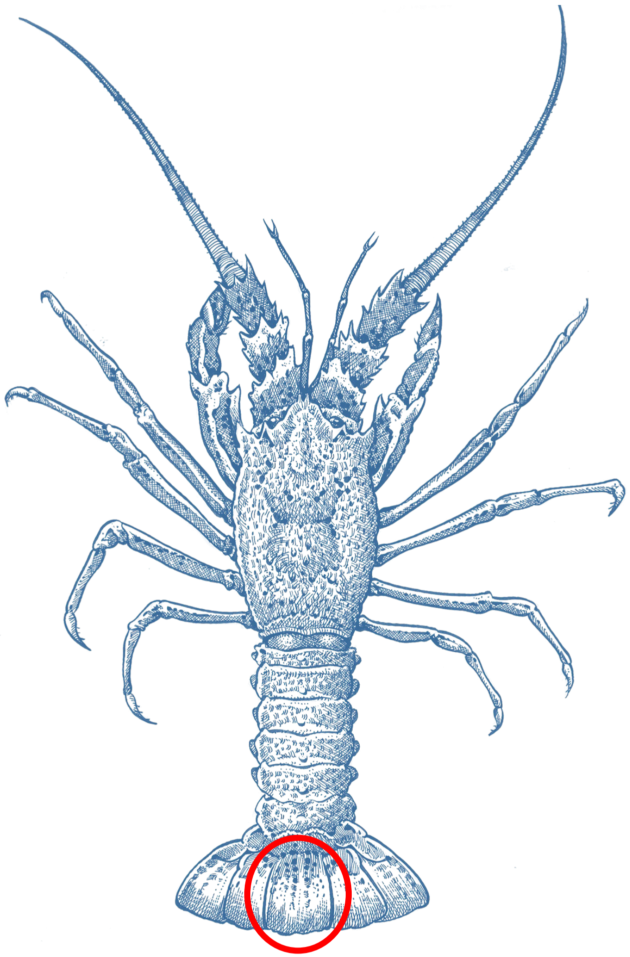

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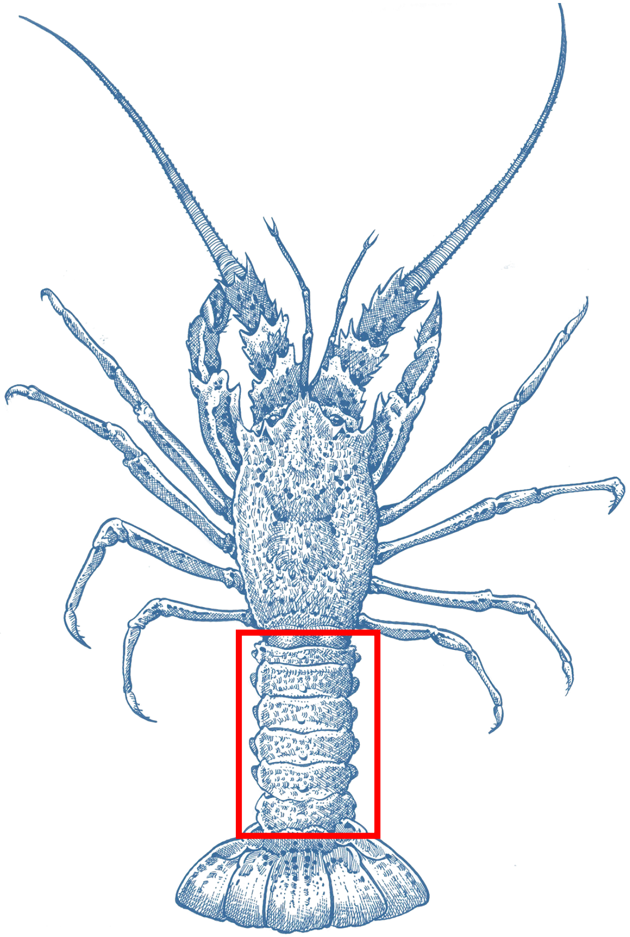

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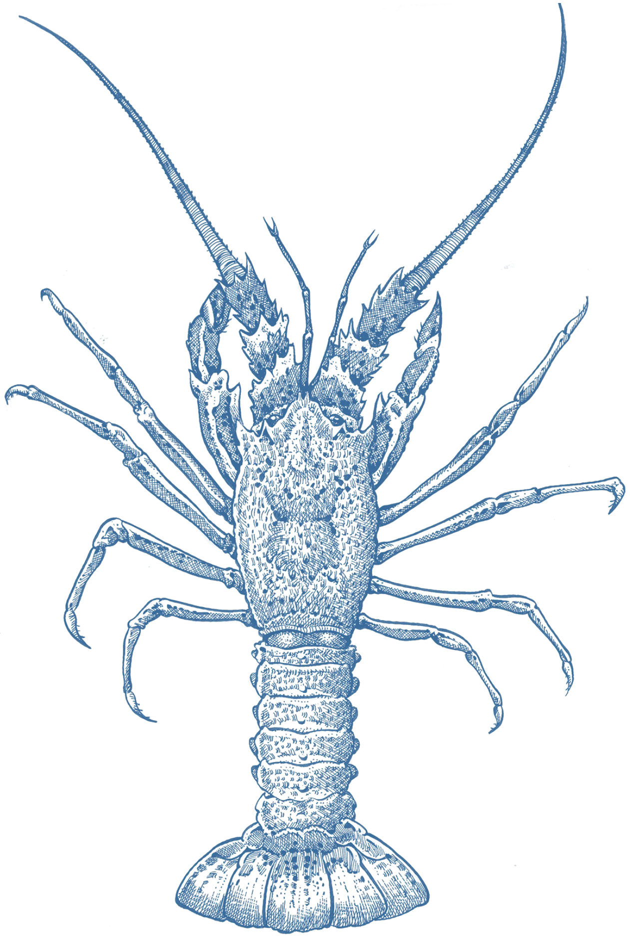

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- Size change (carapace length)
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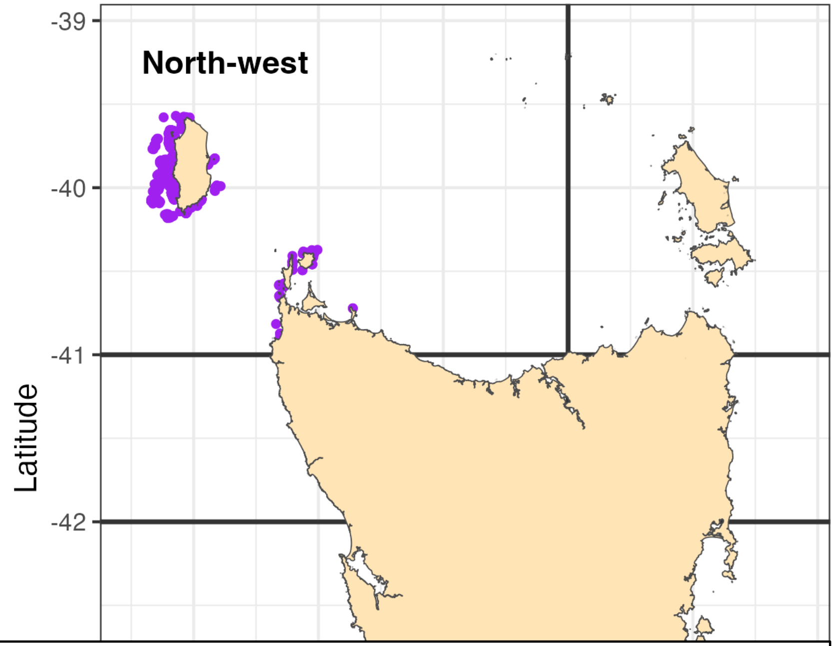
- Evidence of sexual maturity change (female)

Aim to use these "indicators" to estimate "when" moulting has occurred

Method: Data (When to Harvest)

- Capture-tag-recapture data used to filter records / animals for **time periods ≤ 18 months**
- Generated data created to **validate methodology**
- Results following will discuss the **North-west**



Location	Sex	Qty	Growth (mm)		Qty Damage		Qty Pleopod		Qty Maturity	
			$\bar{x}$	sd	0	1	0	1	0	1
North-west	Female	1979	5.9	6.4	24	12	114	47	-	277
North-west	Male	2061	10.4	8.3	41	7	130	60	-	-

Method: HMM (When to Harvest)

- A Hidden Markov Model was created in STAN (within R)
- Hidden states in the model represent whether a lobster has moulted
- Moulting is never directly observed but inferred from the data

Probability of having moulted

$$\theta_i = 1 - \prod_{j=1}^{12} (1 - p_j)^{t_{i,j}}$$

Unobserved outcome of whether MOULTING occurred

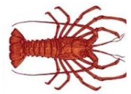
$$M_i \sim \text{Bernoulli}(\theta_i)$$

Expected moult periods (from literature)

Male Moult Period

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Female Moult Period

Example lobster 

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

t for these months (if whole) = 1

Capture **ReCapture**

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Prob not moulting in any month

Probability of having moulted

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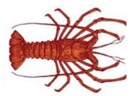
Example lobster 

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Capture

Recapture

Method: HMM (When to Harvest)

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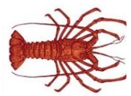
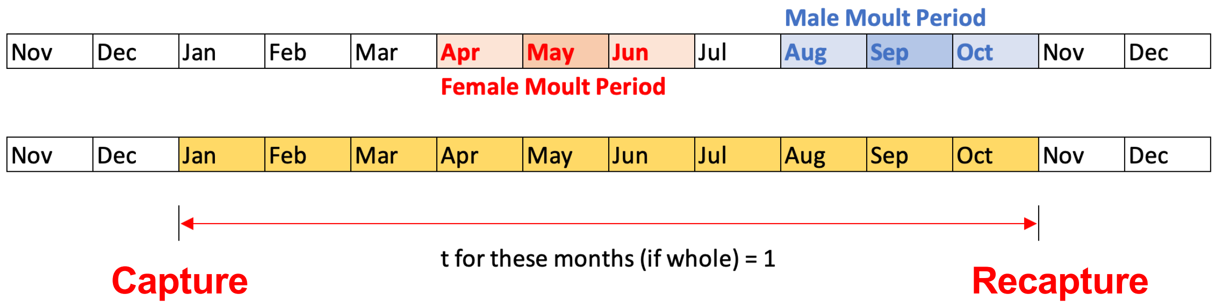
```
for (iLobster in 1:nLobsters){
    //Expression for moulting (time periods as months)
    real probNotMoulted = 1;
    real probmoulted;
    for (iPeriod in 1:nPeriods){
      probNotMoulted*=pow((1-p[iPeriod]),atLiberty[iLobster,iPeriod]);
    }
    probmoulted=1-probNotMoulted;
```

Expected moult periods (from literature)

Example lobster





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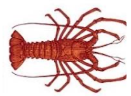
Expected moult periods (from literature)

Male Moult Period: Aug, Sep, Oct

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Female Moult Period: Apr, May, Jun

Example lobster 

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Capture (Jan) → t for these months (if whole) = 1 → **Recapture** (Nov)

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Probability of having moulted

$$\theta_i = 1 - \prod_{j=1}^{12} (1 - p_j)^{t_{i,j}}$$

Unobserved outcome of whether MOULTING occurred

$$M_i \sim \text{Bernoulli}(\theta_i)$$

Evidence (Capitals) are observed

GROWTH

$$G_i \sim \begin{cases} \mathcal{N}(\mu_m, \sigma_m) & \text{if } M_i = 1 \\ \mathcal{N}(0, \sigma_n) & \text{if } M_i = 0 \end{cases}$$

DAMAGE

$$D_i \sim \begin{cases} \text{Bernoulli}(d_m) & \text{if } M_i = 1 \\ \text{Bernoulli}(d_n) & \text{if } M_i = 0 \end{cases}$$

PLEOPOD

$$P_i \sim \begin{cases} \text{Bernoulli}(p_m) & \text{if } M_i = 1 \\ \text{Bernoulli}(p_n) & \text{if } M_i = 0 \end{cases}$$

FEMALE MATURITY

$$F_i \sim \begin{cases} \text{Bernoulli}(f_m) & \text{if } M_i = 1 \\ \text{Bernoulli}(f_n) & \text{if } M_i = 0 \end{cases}$$

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```
//MOULTED & GROWTH INCREMENT EVIDENCE
target += log(
  //Likelihood of moulting
  exp(
    bernoulli_lpmf(1 | probmoulted) +
    normal_lpdf(obsGI[iLobster] | growth_mu, growth_sigma)
  )+
  //Likelihood of NOT moulting
  exp(
    bernoulli_lpmf(0 | probmoulted) +
    normal_lpdf(obsGI[iLobster] | 0, nogrowth_sigma)
  )
);
```

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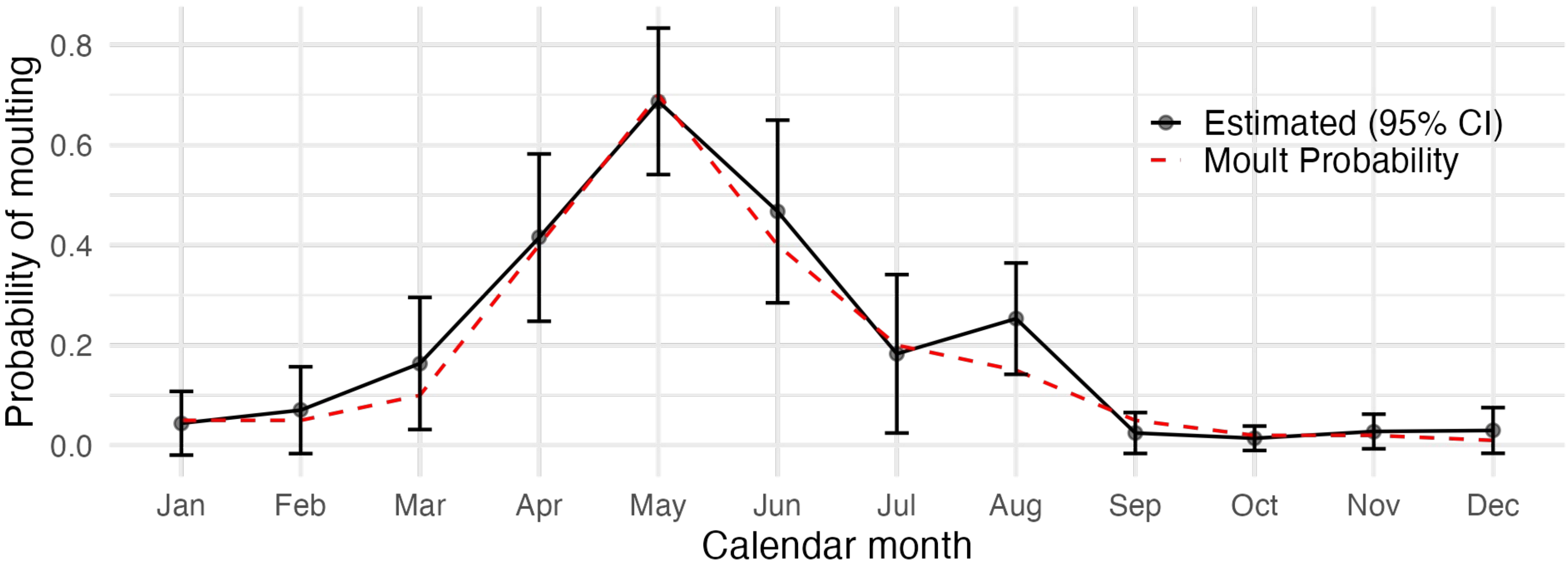
);
```

Results: Generated (When to Harvest)

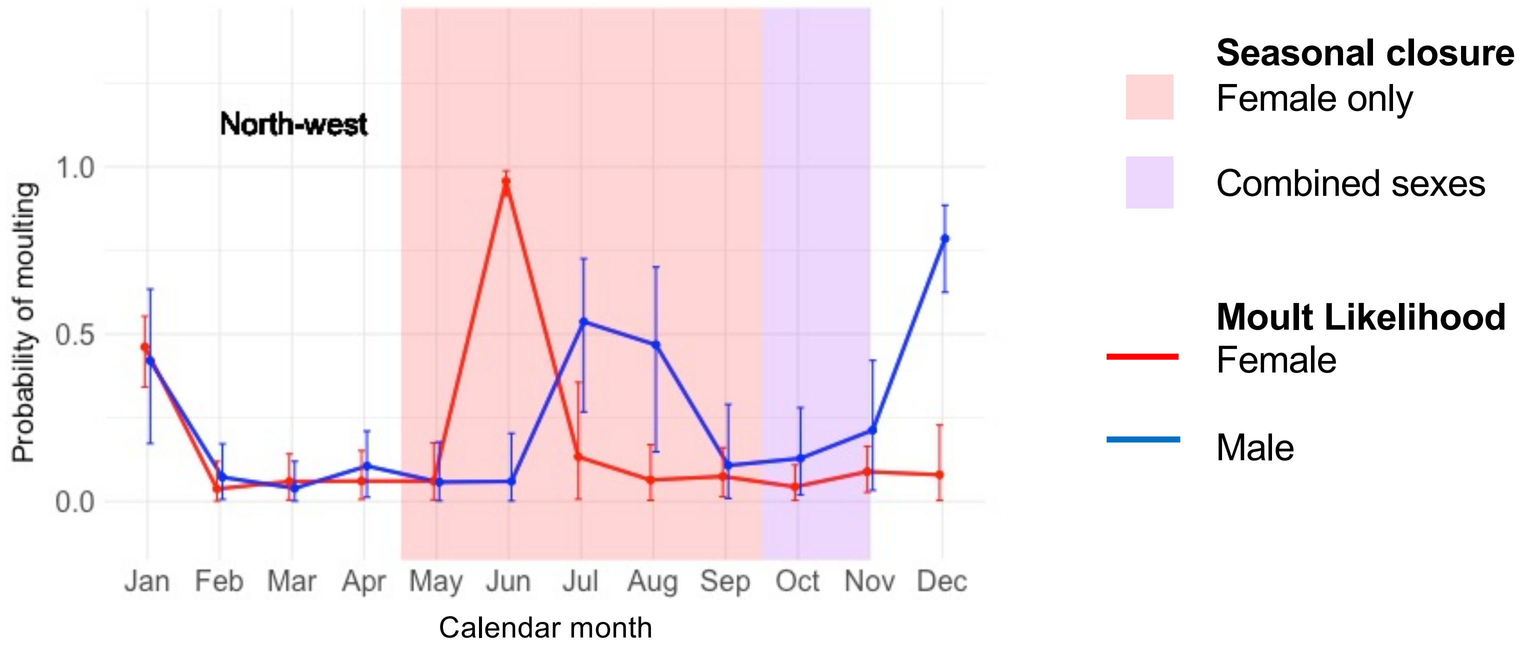
- N=1000 animals used for generated data (representative of female moult behaviour)



Results: Fishery (When to Harvest)

- Proportion of animals receiving some benefit from the closure

Location	North-west
Female	68%
Male	11%



Conclusion (When to Harvest)

- **Flexible framework**
    - Time period pooling
    - Suitable for a broad range of species
- **Recommendations**
    - Review closure timings
    - More rigor required in complete data records (missed opportunities in data)
    - Time-boxing data to better understand temporal change / half-decadal changes

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Thank you