# Survival of discarded invertebrates from bottom trawling fisheries in the Bay of Biscay

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– 21 octobre 2019 –

*Picture ictioterm.es / A.M. Arias*

Ifremer

Dorothée Kopp
Sonia Méhault
Marie Morfin

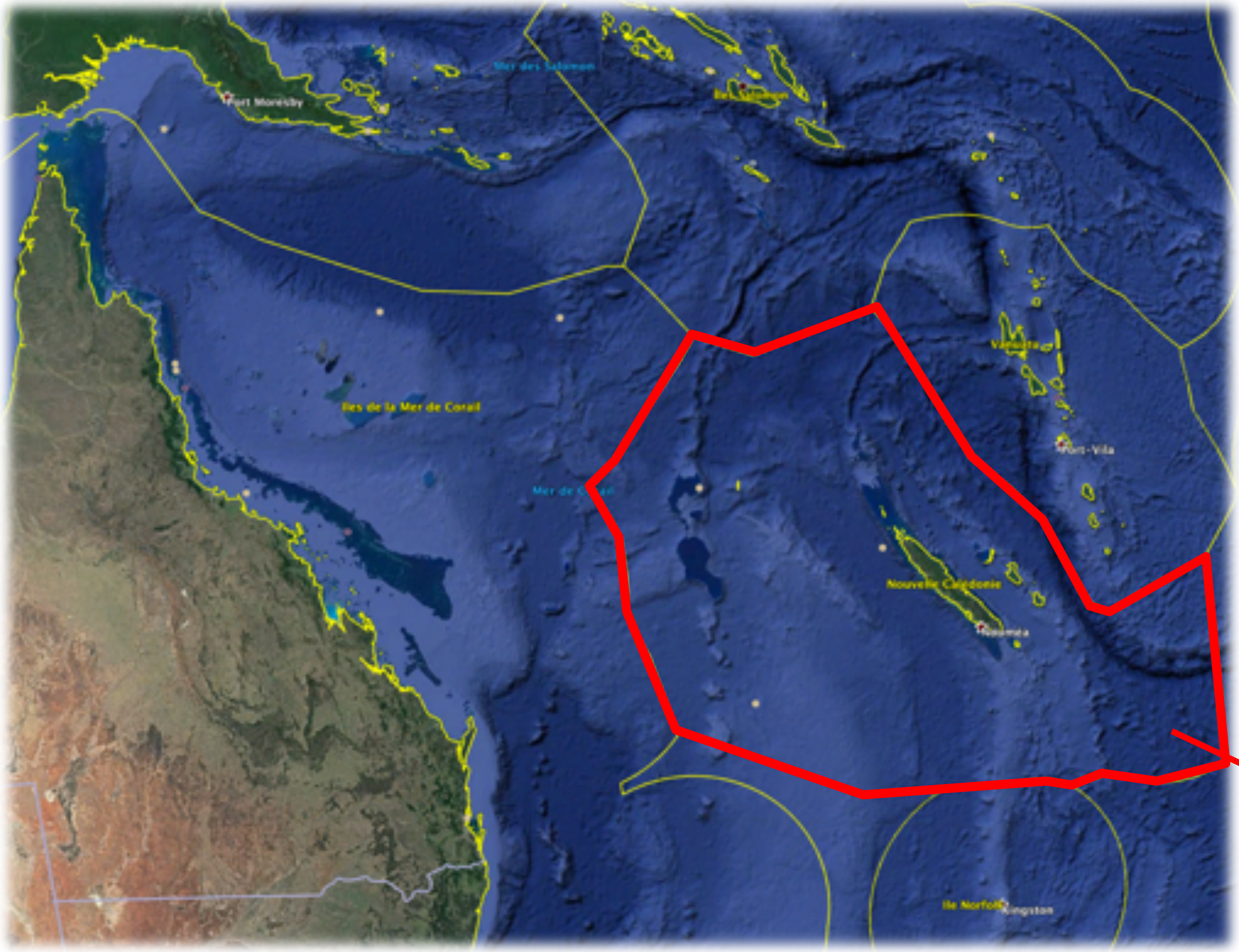
@g_boussarie

# Projet APEX

Requins de récifs
de Nouvelle-Calédonie

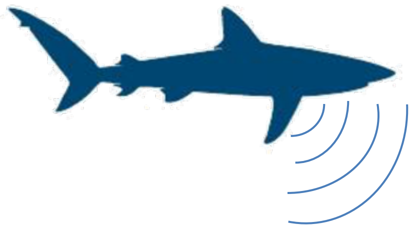
Optimiser les efforts
de conservation

Parc naturel de la mer de Corail



1,4 millions de km$^2$

*Nouvelle-Calédonie (Archipel)*



Télémétrie Acoustique

Génétique des populations

Ecologie Trophique

ADN Environnemental

# Projet DREAM :
# Devenir des Rejets : de l'Air au fond de la Mer

Dorothée Kopp & Sonia Méhault

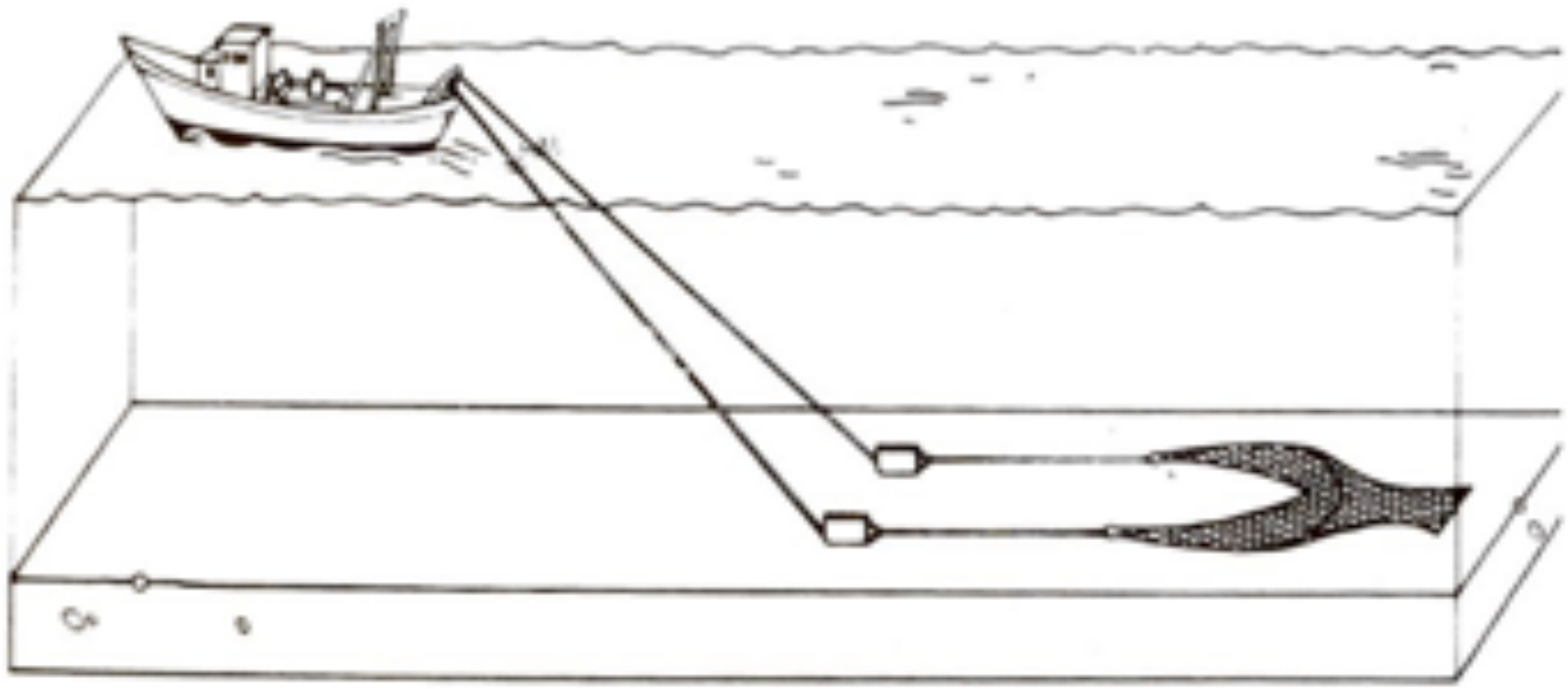
- Integrative approach
    - Focus on commercial and non-commercial species
    - Predation on discards (aerial, pelagic and benthic)

## BOTTOM TRAWLING…

*"Bottom trawling is the most widespread human activity directly affecting seabed habitats"*

*"Assessment and effective management of the effects of bottom trawling at the scale of fisheries requires an understanding of differences in sensitivity of biota to trawling"*

*Hiddink et al. 2019*



Adapted from "Quaderns d'Ecologia Aplicada", by M. Armadura de Suras Demestre, 1986 and National Oceanic and Atmospheric Administration, 2018

## BOTTOM TRAWLING… AND KNOWLEDGE GAPS

*"Bottom trawling is the most widespread human activity directly affecting seabed habitats"*

*"Assessment and effective management of the effects of bottom trawling at the scale of fisheries requires an understanding of differences in sensitivity of biota to trawling"*

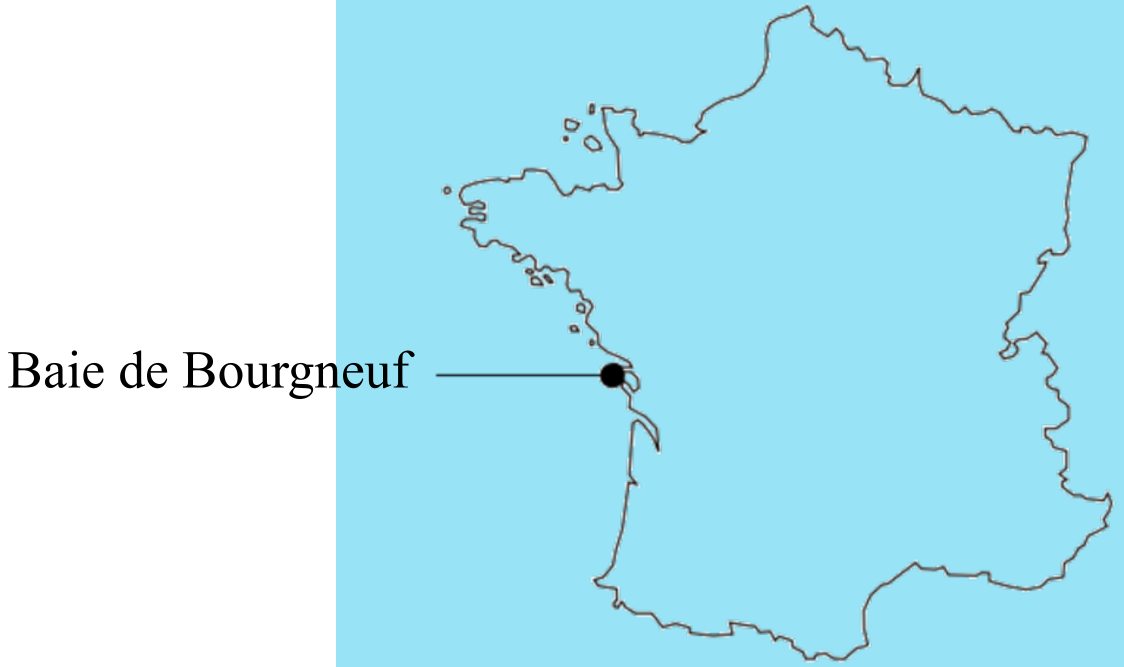
*Hiddink et al. 2019*

- Search in Web of Science : 'survival + discard* + fish + trawl'
  - 124 or 296 ('~~trawl~~')
- Search in Web of Science : 'survival + discard* + invertebrates + trawl'
  - 17 or 23 ('~~trawl~~')

Lack of knowledge on the impact of trawling
on survival of benthic invertebrates

## SAMPLING IN COMMERCIAL CONDITIONS

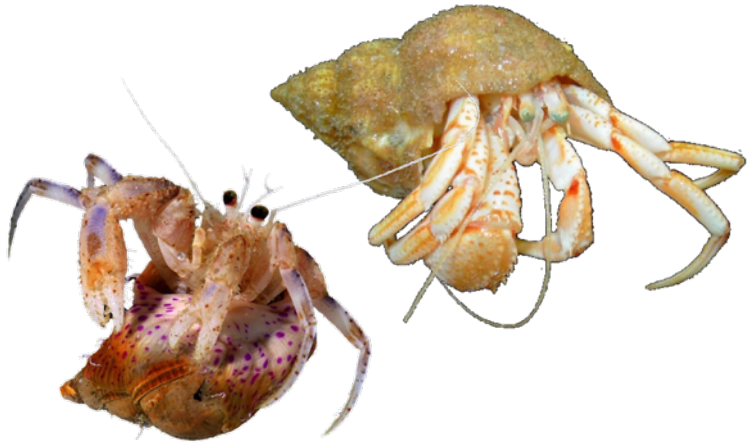

- Aboard the *Déesses de l'Océan*, 10.95m French coastal trawler with 150 kW power engine
- Bay of Bourgneuf (Bay of Biscay)
  - Single otter trawl (20 m headline and 70 mm diamond mesh codend)
  - 3 days in April (daily trips)
  - 11 hauls (5 - 22 m depth ; 85 – 141 min)



## SELECTED BENTHIC INVERTEBRATE SPECIES

*Maja brachydactyla*

*Atelecyclus undecimdentatus*



*Pagurus*

*Asterias rubens*

*Aphrodita aculeata*

*Buccinum undatum*

*Pictures ictioterm.es A.M. Arias, Ifremer G. Paulmier, J. Martin, H. Hillewaert*

# PRELIMINARY RESULTS : INJURIES

| | Injury class 1 | Injury class 2 | Injury class 3 | Injury class 4 |
|---|---|---|---|---|
| *Asterias rubens* | No visible damage | Arms missing | Minor disc damage | Crushed |
| *Maja brachydactylus* | No visible damage | Legs missing | Major carapace cracks | Crushed |
| *A. undecimdentatus* | No visible damage | Legs missing | Major carapace cracks | Crushed |
| *Aphrodita aculeata* | No visible damage | Visible damage | Crushed | - |
| *Pagurus* | No visible damage | Edge of shell chipped | Shell cracked/punctured | Crushed |
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*Adapted from Veale et al. 2001 and Depestele et al. 2014*

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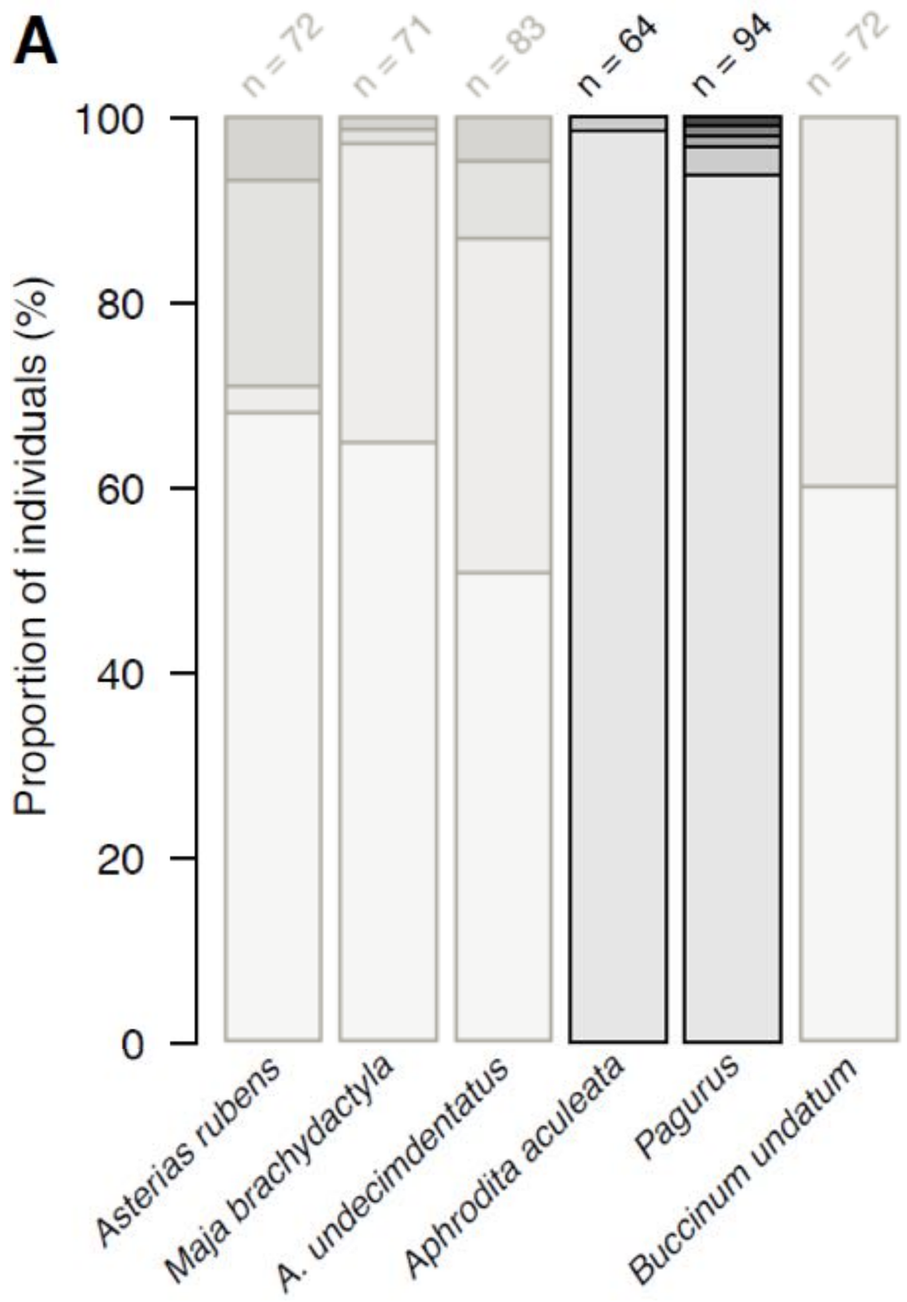


➡ Very little visible impact on *Aphrodita* and *Pagurus*

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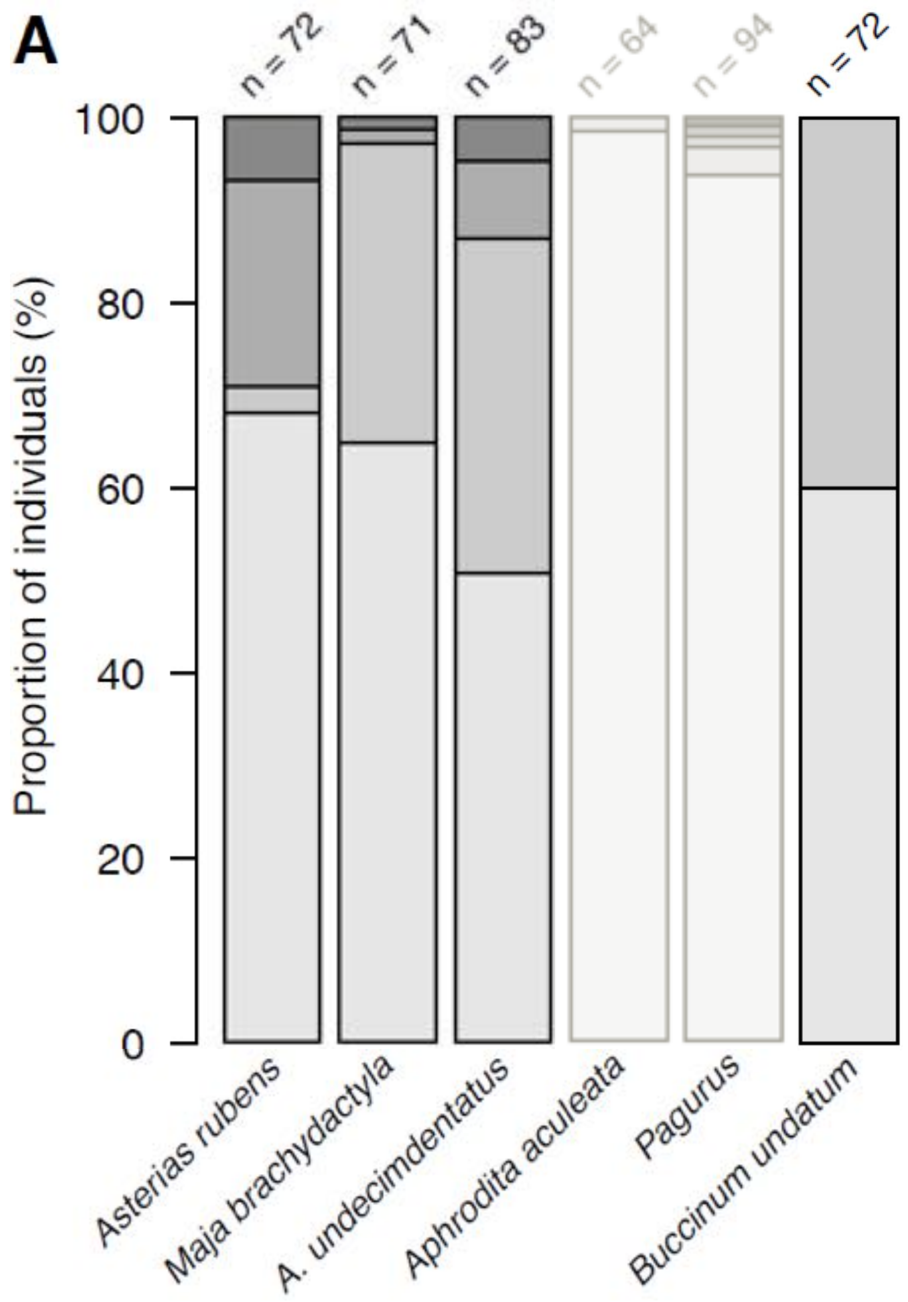


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- Non-negligible impact of trawling (visible injuries)

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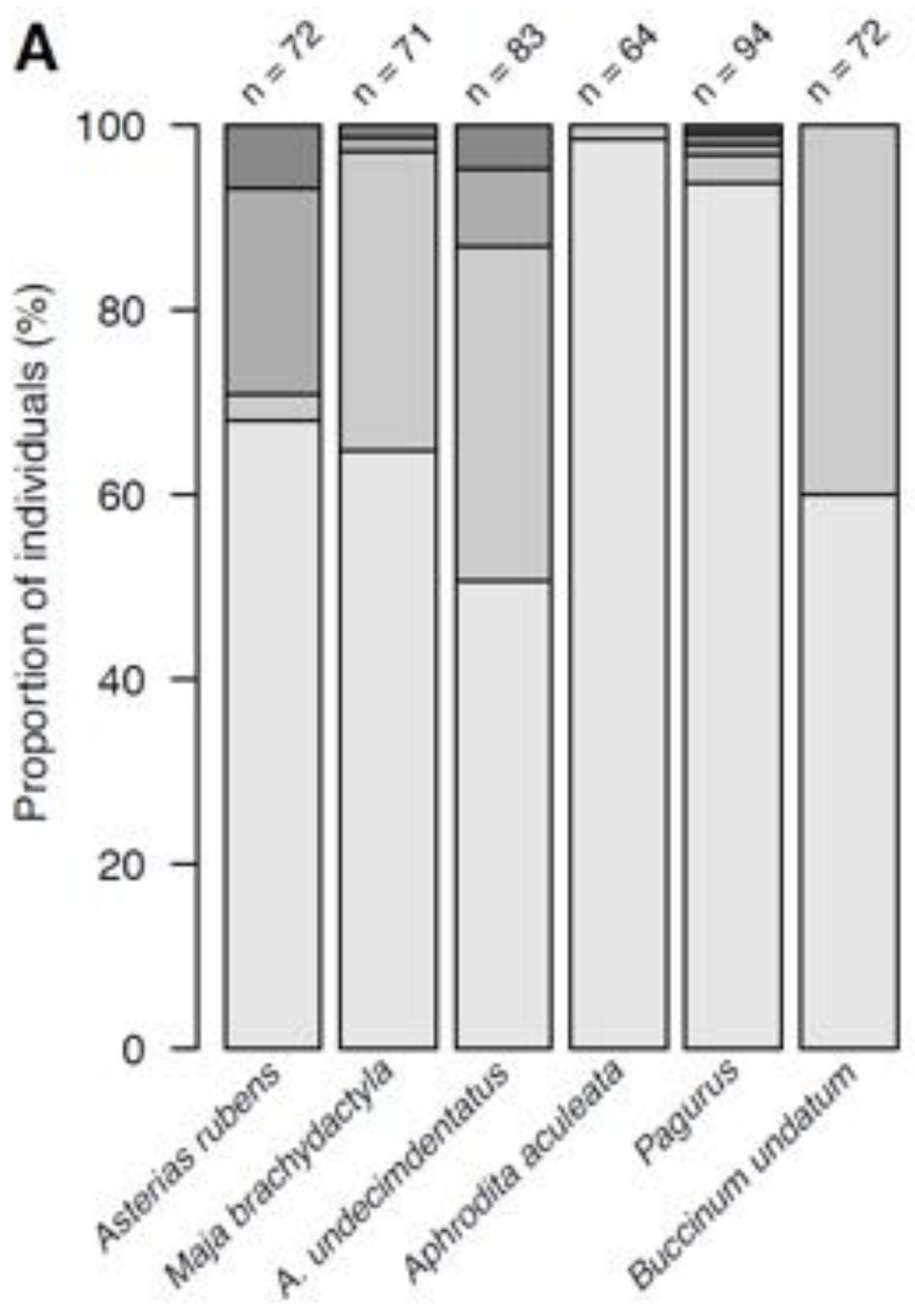
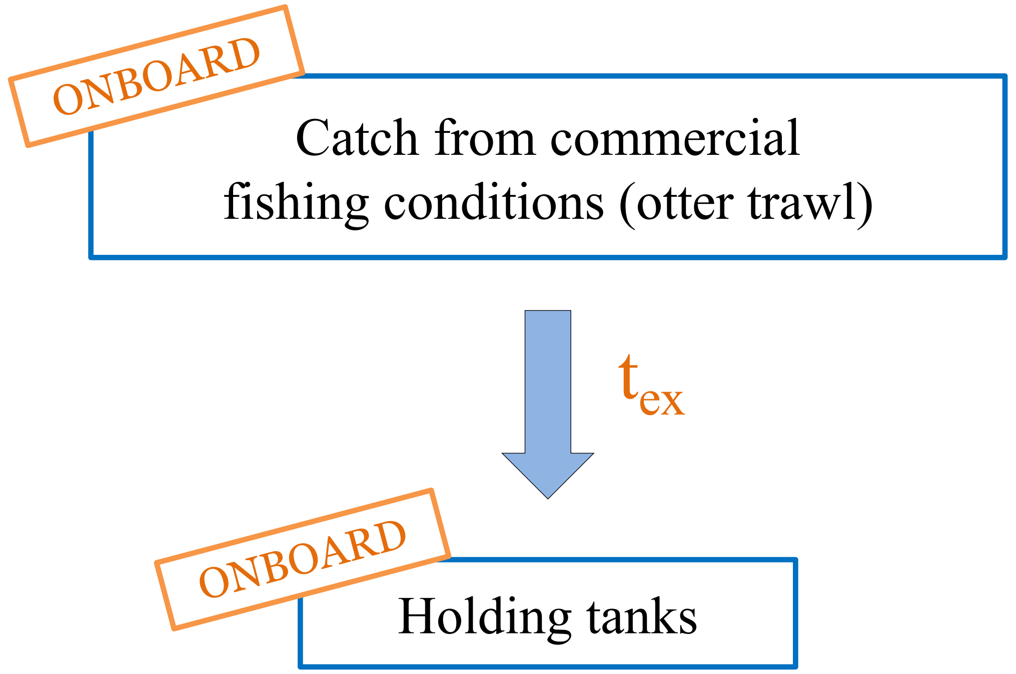



- Very little visible impact on *Aphrodita* and *Pagurus*
- Non-negligible impact of trawling (visible injuries)
- Only direct and visible impact

# SURVIVAL EXPERIMENTS



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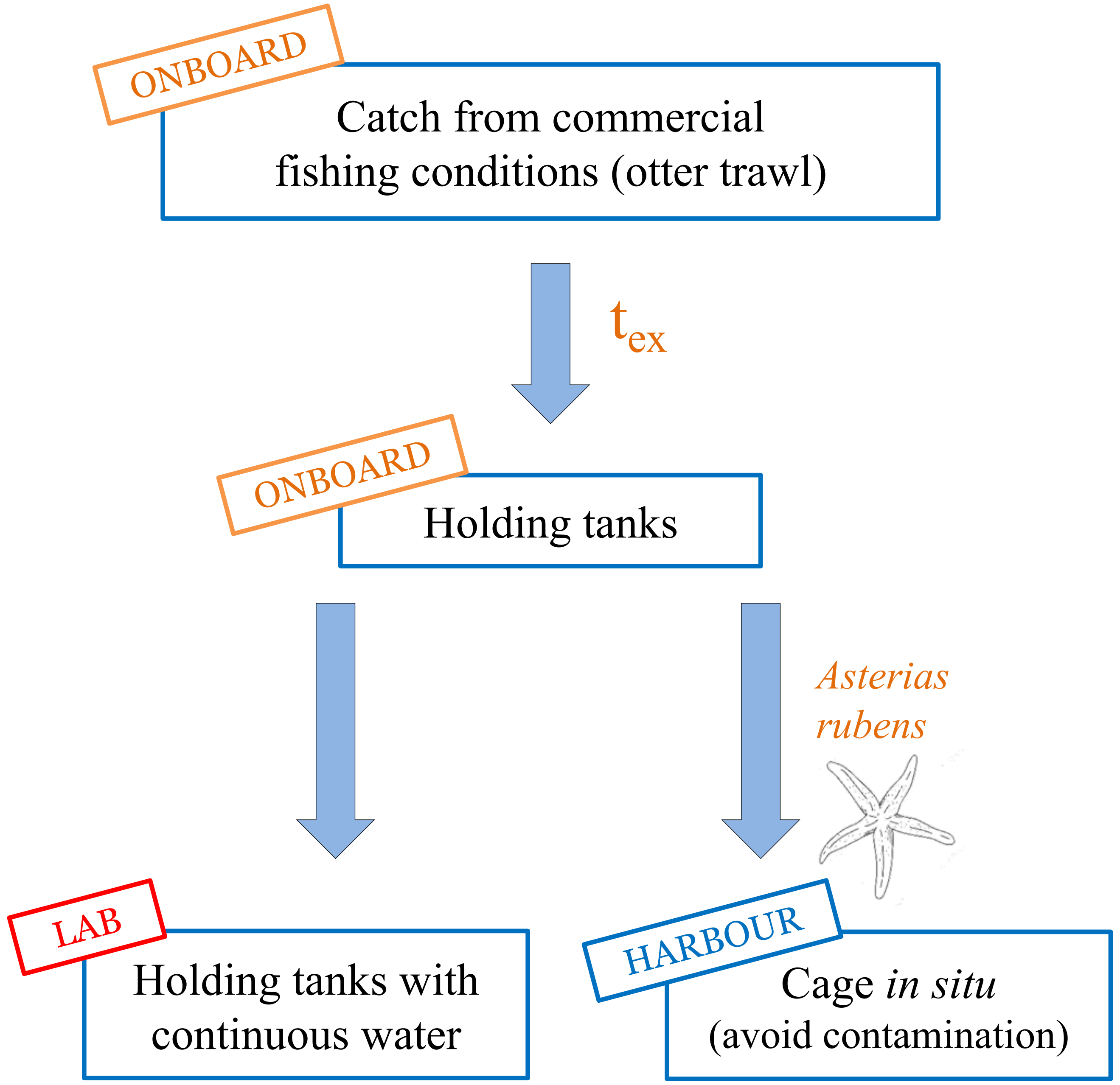

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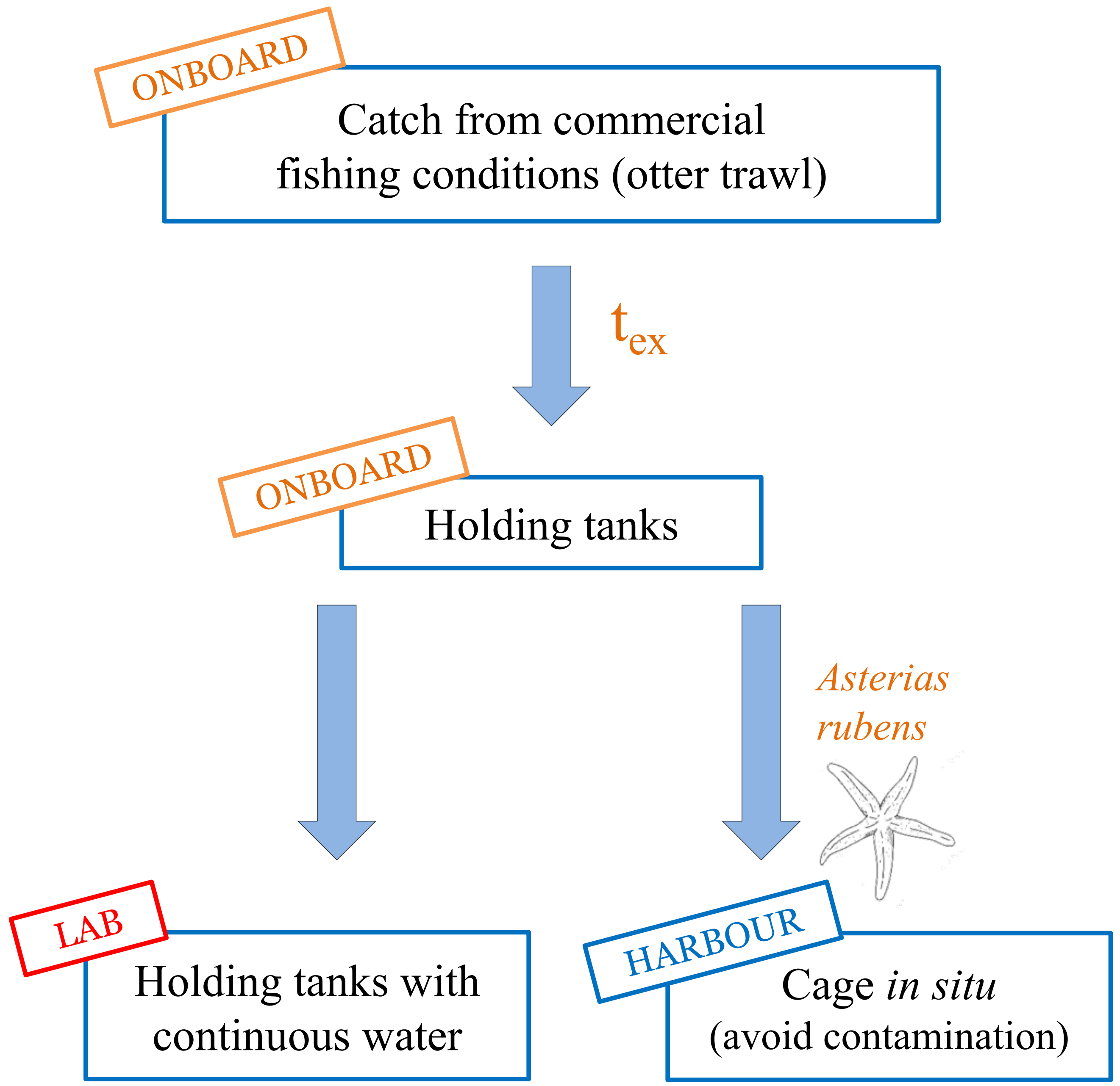



- Mortality assessment twice a day (~12h)
- Daily control of water quality

# SURVIVAL EXPERIMENTS

ONBOARD — Catch from commercial fishing conditions (otter trawl)

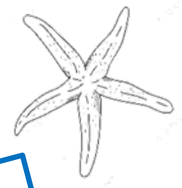
↓ $t_{ex}$

ONBOARD — Holding tanks

↓ LAB — Holding tanks with continuous water

*Individual identification*

↓ *Asterias rubens*



HARBOUR — Cage *in situ* (avoid contamination)


*All individuals of the same species from a single trait were stored in single crates, individually marked or stored, and monitored twice a day*

- Mortality assessment twice a day (~12h)
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$t_{ex}$

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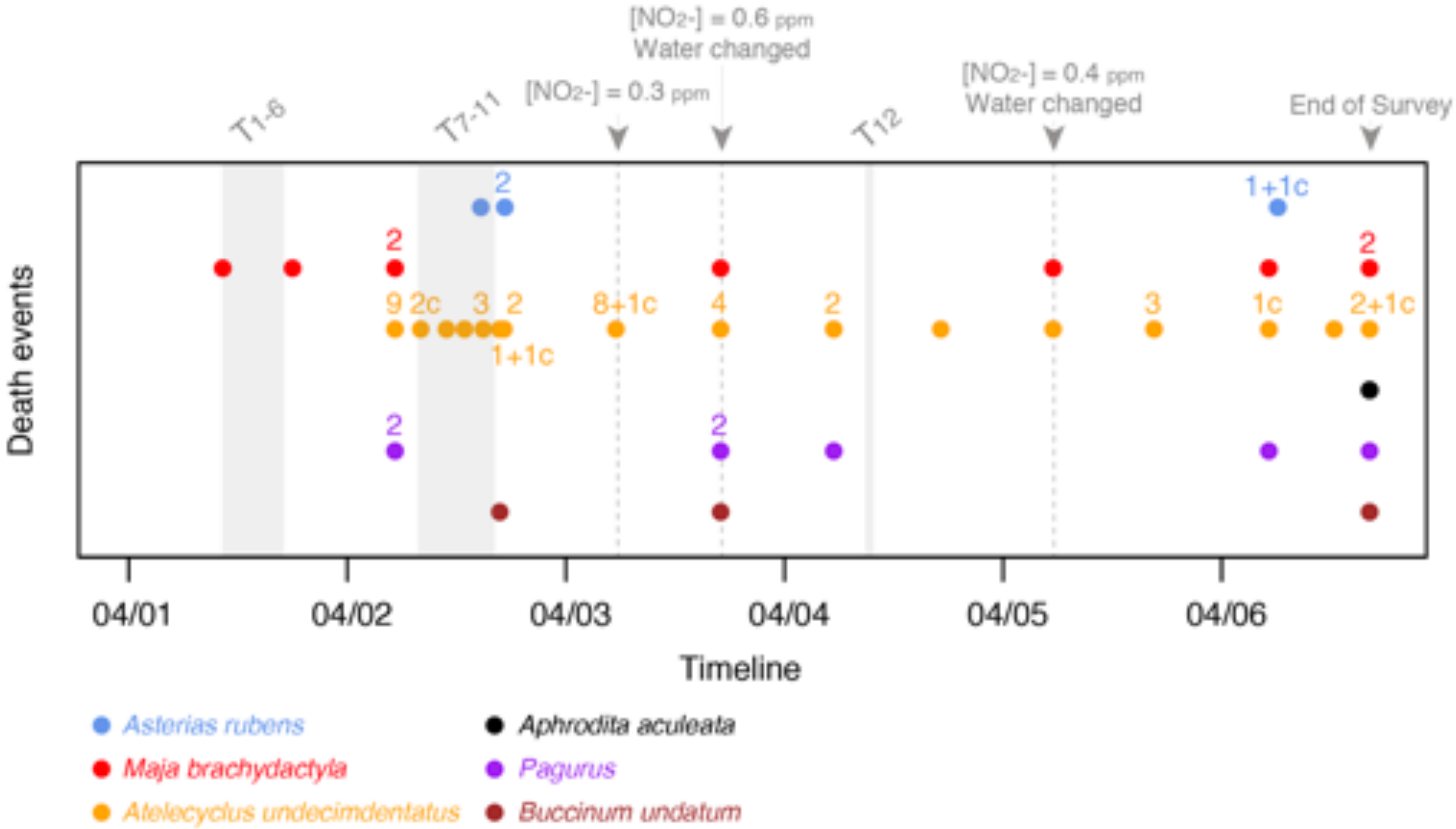
## CONTROLS

Short hauls (< 25 min)


Creels




# TIMELINE


[NO2-] = 0.6 ppm
Water changed
[NO2-] = 0.3 ppm
[NO2-] = 0.4 ppm
Water changed
End of Survey
T1-6
T7-11
T12
Death events
2
2
1+1c
2
9 2c 3 2
8+1c
4
2
3
1c
2+1c
1+1c
2
2
04/01
04/02
04/03
04/04
04/05
04/06
Timeline
Asterias rubens
Maja brachydactyla
Atelecyclus undecimdentatus
Aphrodita aculeata
Pagurus
Buccinum undatum

## SURVIVAL AT THE END OF THE EXPERIMENT

*Asterias rubens*

$n_{total} = 72$
$n_{dead} = 4$
$p_{survival} = 94.4\%$

*Aphrodita aculeata*

$n_{total} = 64$
$n_{dead} = 2$
$p_{survival} = 96.9\%$

*Buccinum undatum*

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*Pagurus*

$n_{total} = 71$
$n_{dead} = 8$
$p_{survival} = 88.7\%$

*Maja brachydactyla*

$n_{total} = 83$
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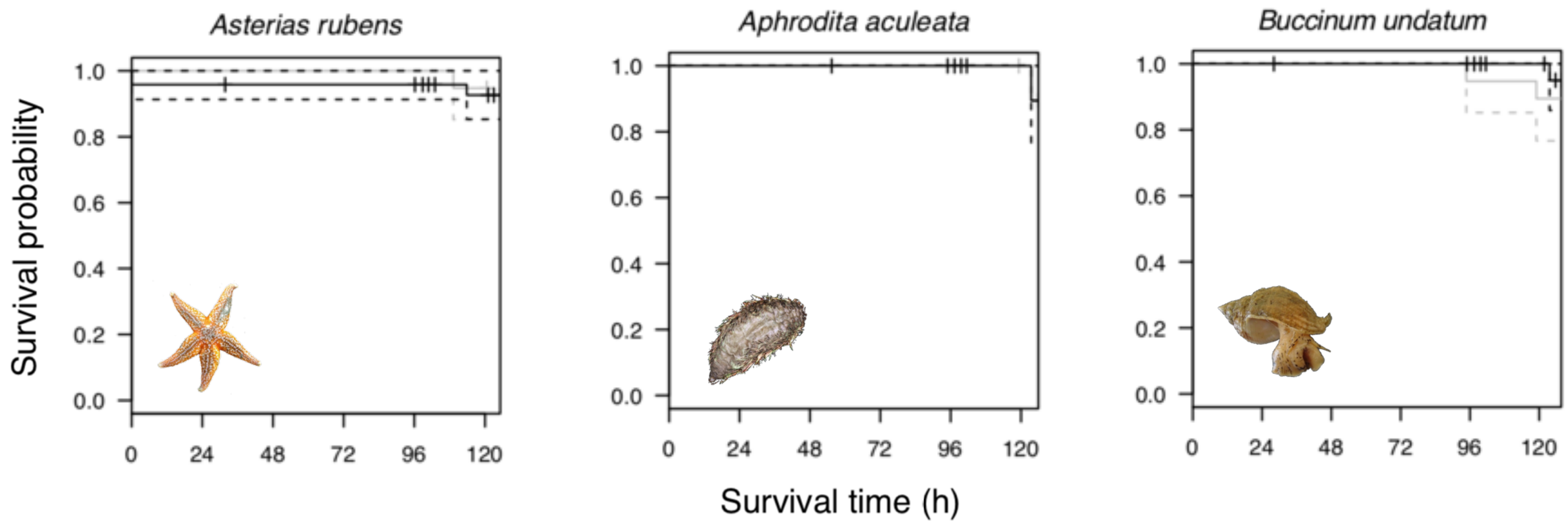
*Atelecyclus undecimduntatus*

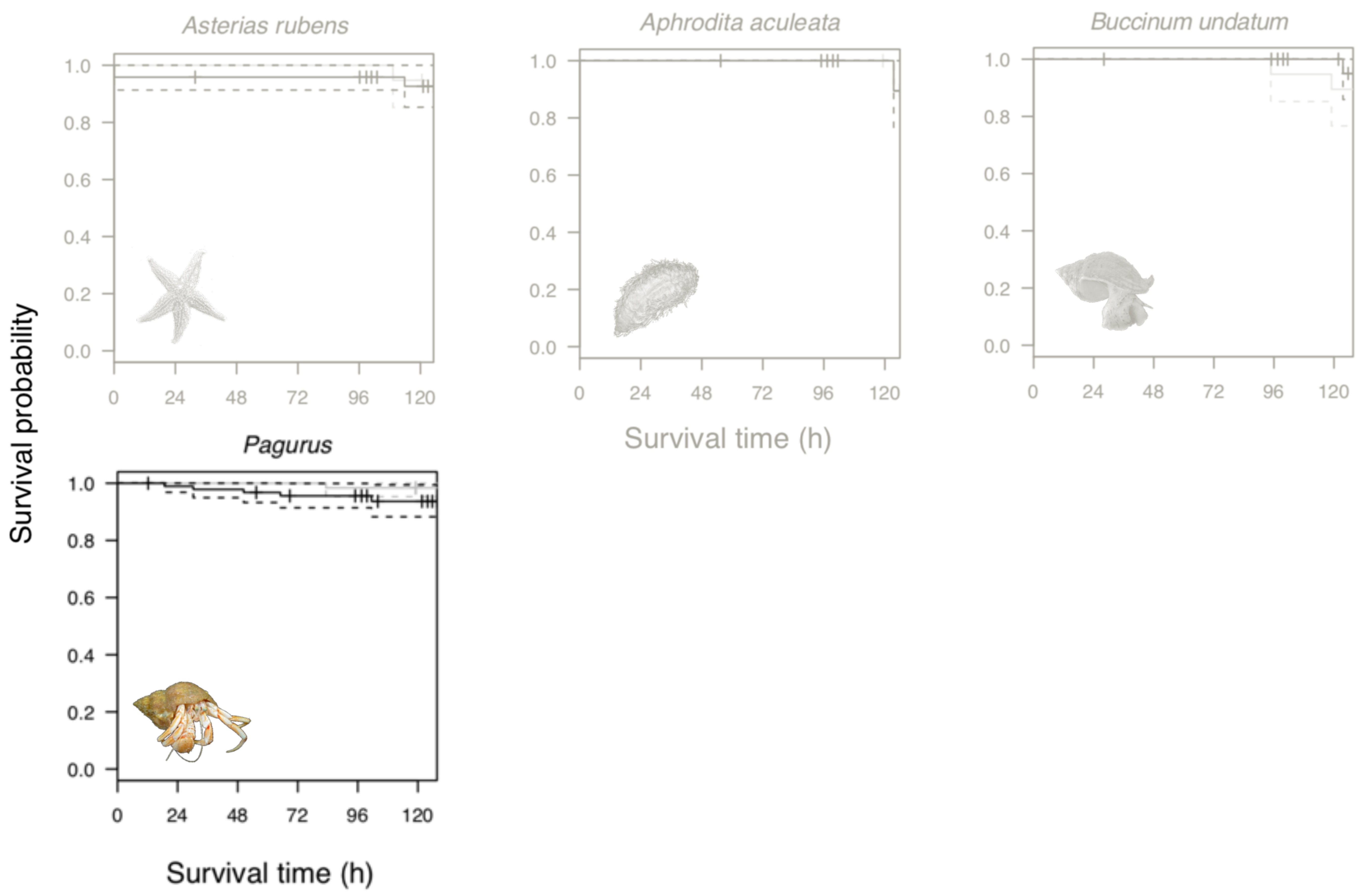
- High ‘survival rate’ ($p_{survival}$) for all except *A. undecimduntatus*
- $p_{survival}$ is informative but biased

## SURVIVAL CURVES (KAPLAN-MEIER)




- Right-censored data : taken into account
- High survival rate for *A. rubens*, *A. aculeata* and *B. undatum*

## SURVIVAL CURVES (KAPLAN-MEIER)



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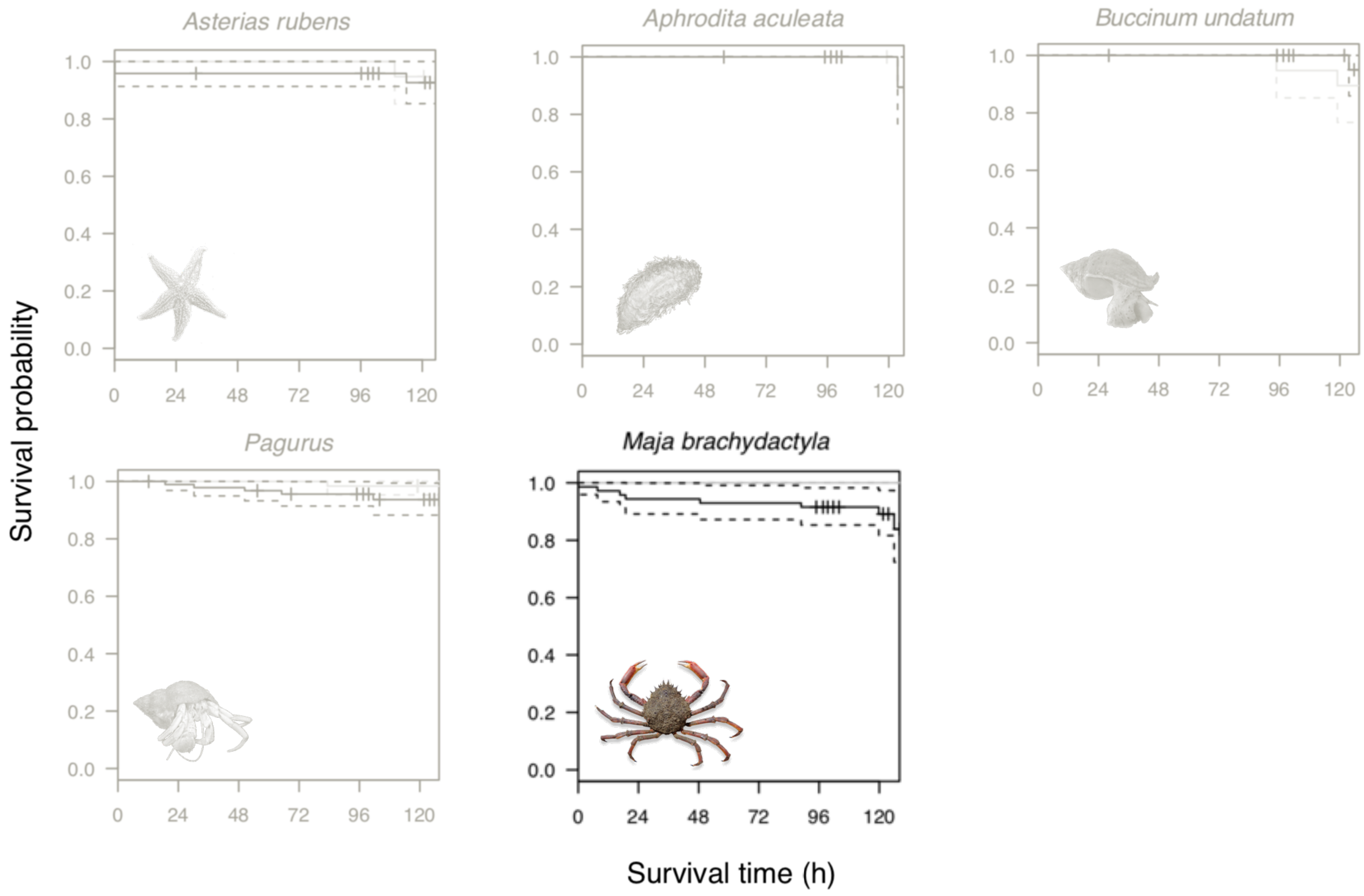

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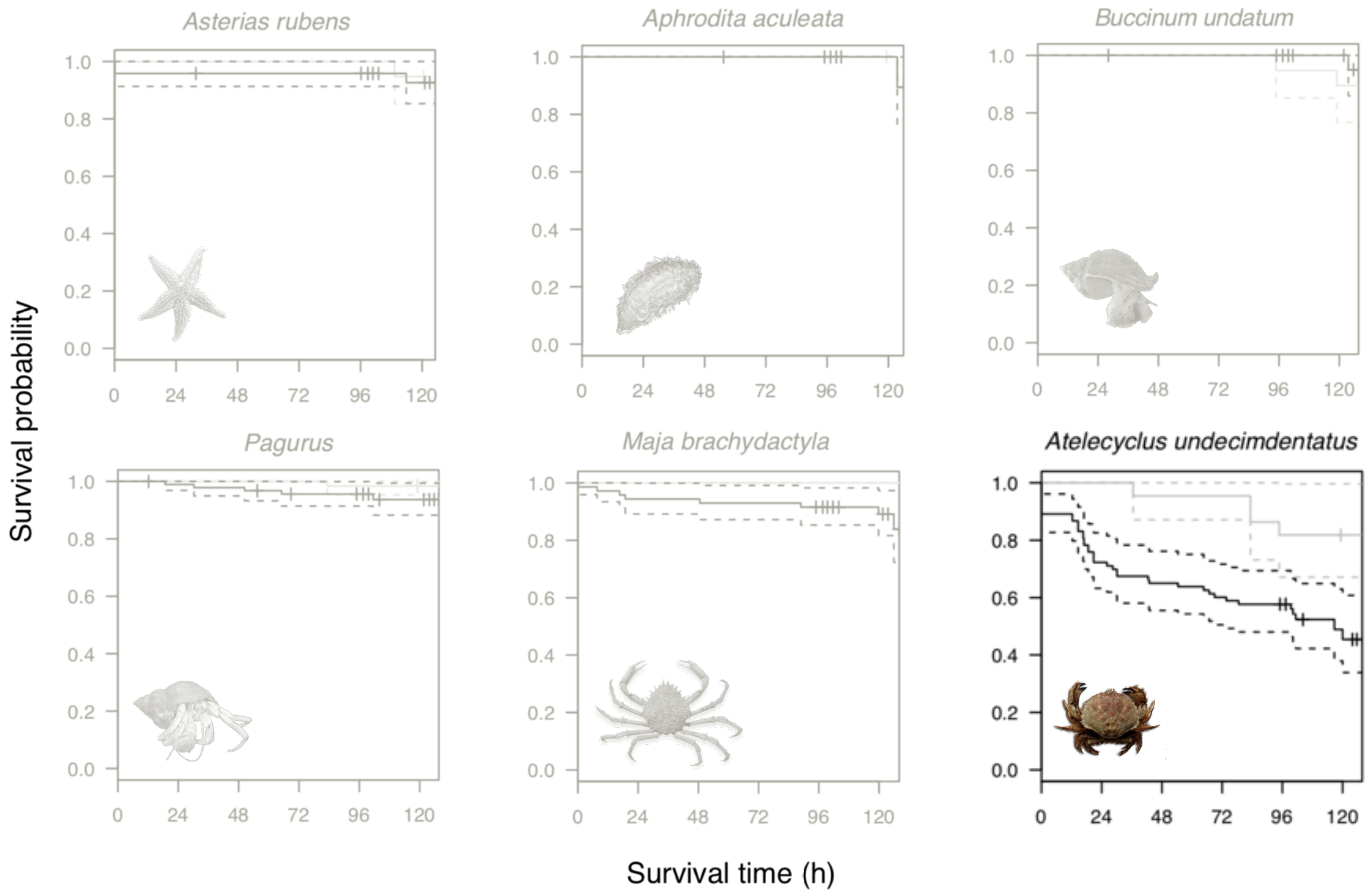

# SURVIVAL MIXTURE MODELS (SMM)

- Survival rate estimated at the end of the experiment

- Weibull-type survival function : $S(t) = \exp[-(\alpha \cdot t)^{\gamma}]$ $\alpha > 0$ $\gamma > 0$

    - All individuals follow the same survival function

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  - ~~All individuals follow the same survival function~~

- Immune and affected individuals :

proportion of affected individuals

$$S'(t) = \pi S_A(t) + (1 - \pi) S_I(t)$$

$S_I(t)$ = 1

$0 \leq \pi \leq 1$

MIXTURE

# SURVIVAL MIXTURE MODELS (SMM)

- ~~Survival rate estimated at the end of the experiment~~

- Weibull-type survival function : $S(t) = \exp[-(\alpha \cdot t)^{\gamma}]$  $\alpha > 0$, $\gamma > 0$

  - ~~All individuals follow the same survival function~~

- Immune and affected individuals : $S'(t) = \pi S_A(t) + (1-\pi) S_I(t)$  $0 \leq \pi \leq 1$

  (proportion of affected individuals: $\pi$; $S_I(t)$ → 1)

  $$S'(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1-\pi)$$

  $\alpha > 0$, $\gamma > 0$, $0 \leq \pi \leq 1$

  MIXTURE

- $\lim_{t \to \infty} S'(t) = 1 - \pi =$ discard survival probability

## SURVIVAL MIXTURE MODELS (SMM)

$$S'(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1 - \pi)$$

MIXTURE

$(\pi, \alpha, \gamma)$ ↓

Maximization of model likelihood,
quasi-Newton optimisation algorithm (*optim*)

*Byrd et al. 1995*

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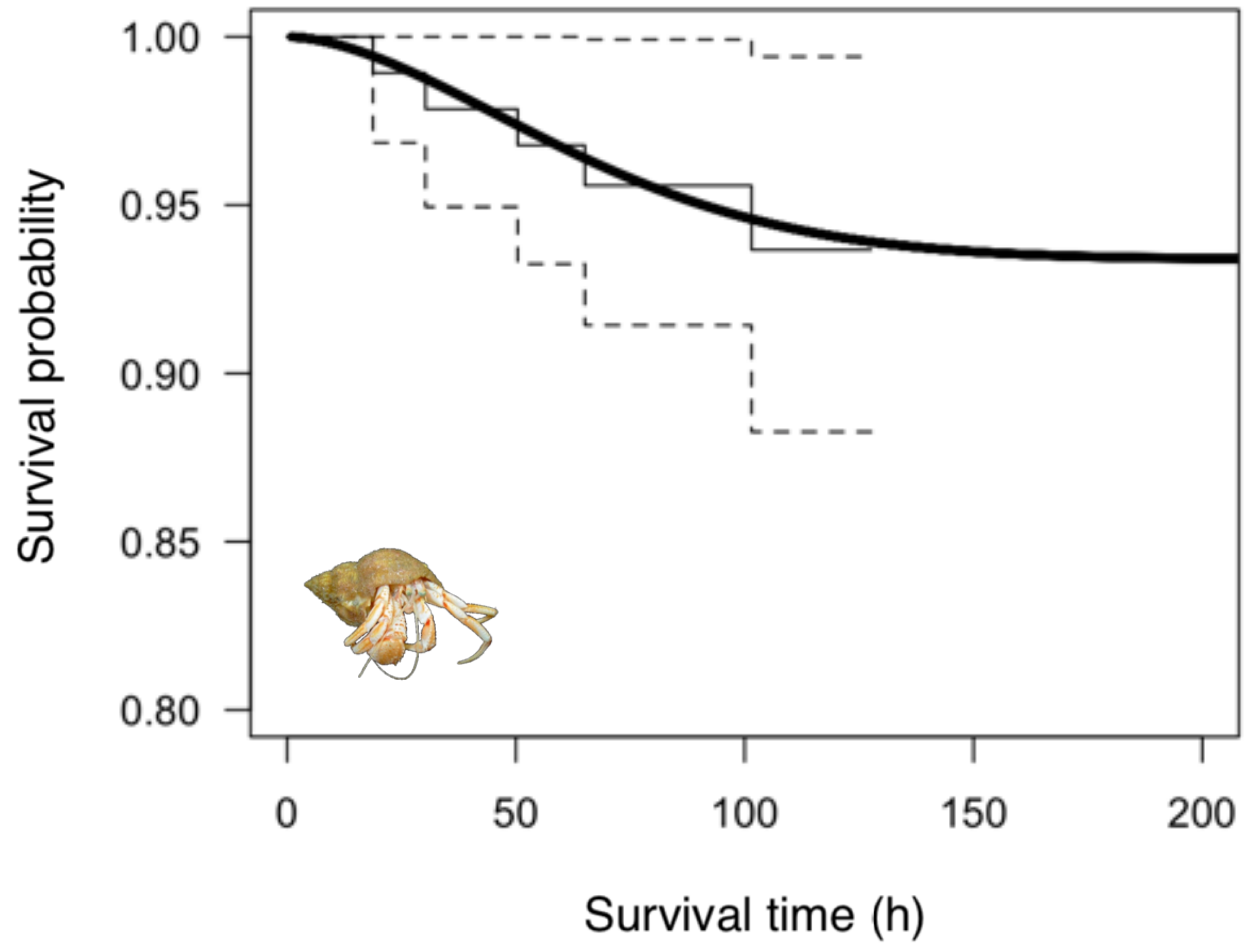
*Pagurus*




$1 - \pi$

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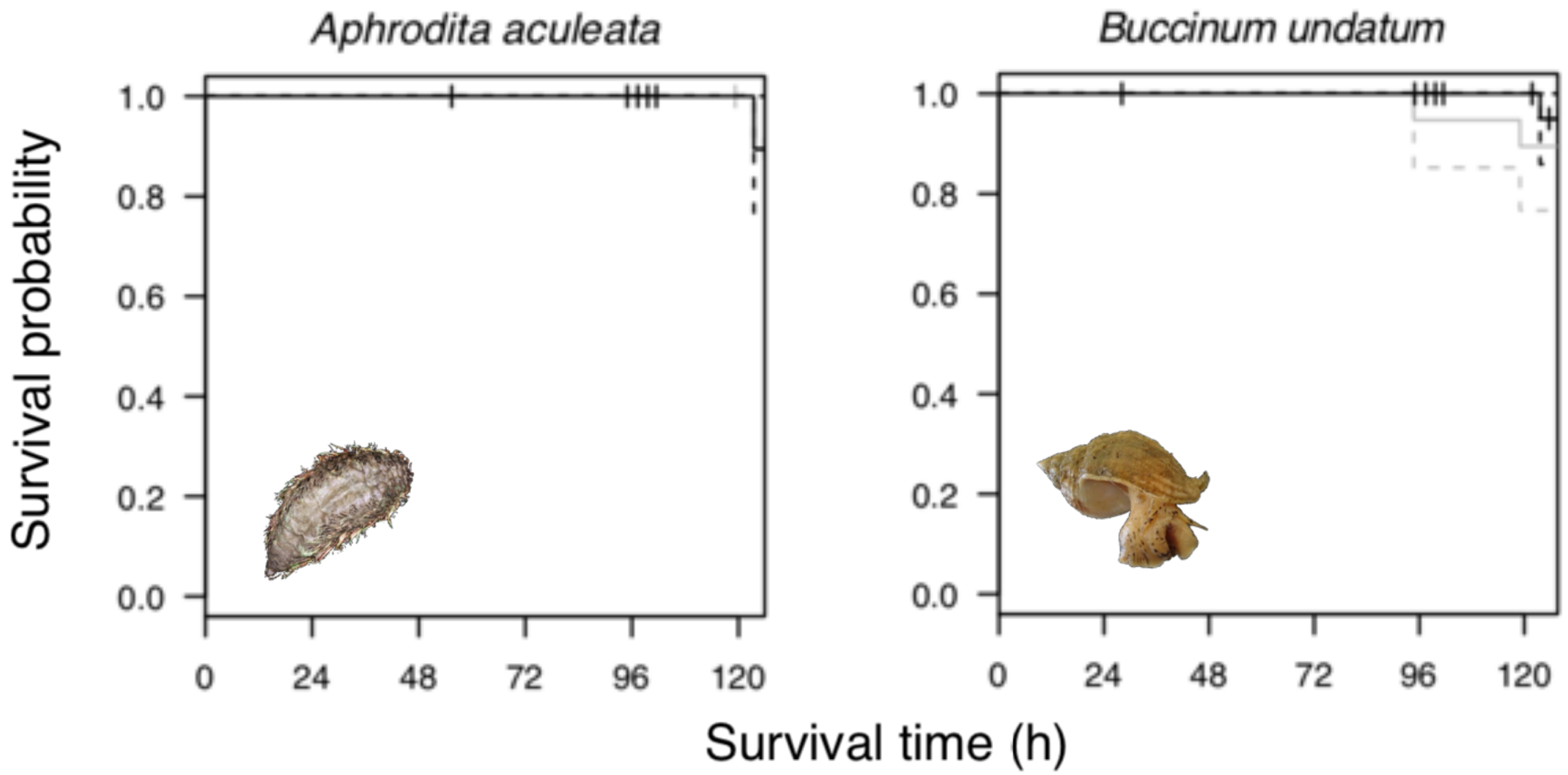


*optim* non-convergent BUT very high survival

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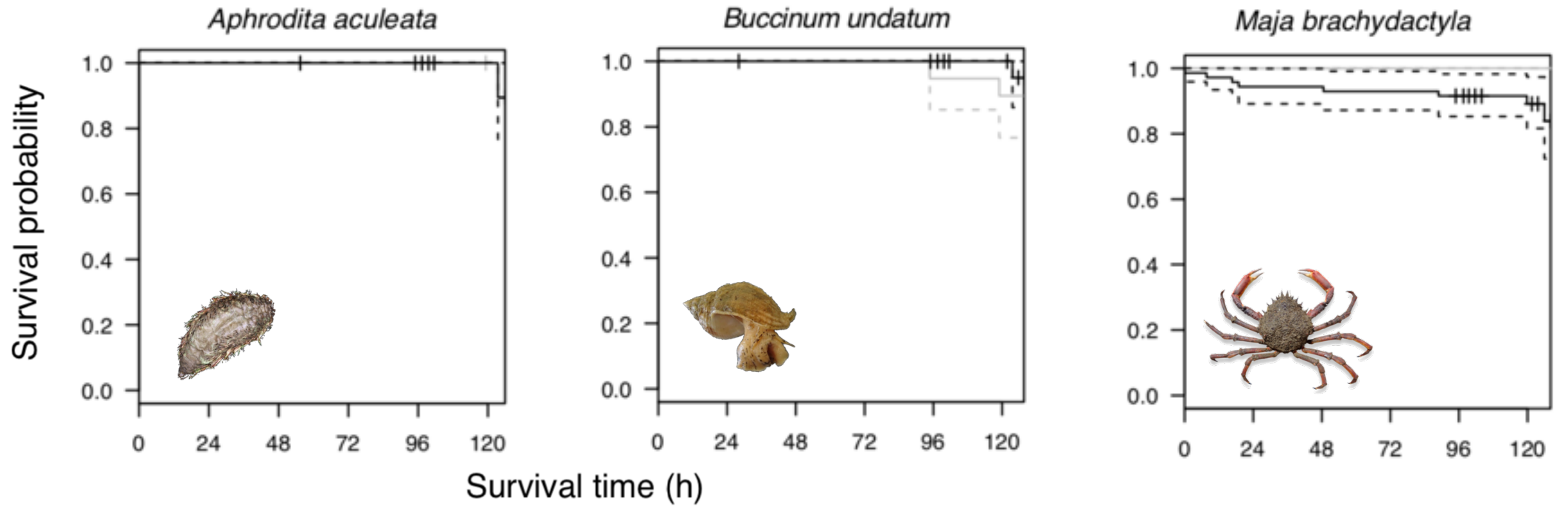


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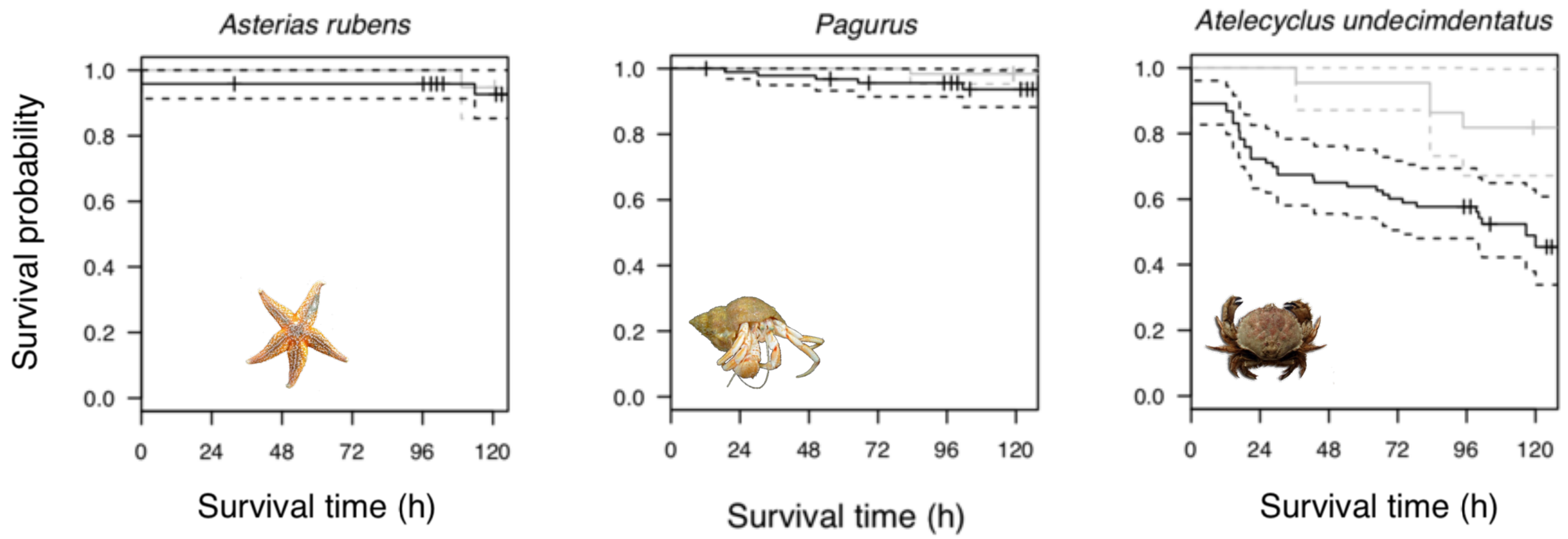


$SMM \Rightarrow \pi = 94\%$

$SMM \Rightarrow \pi = 93\%$

$SMM \Rightarrow \pi = 47\%$

## SURVIVAL DEPENDING ON INJURY CLASSES

| | Injury class 1 | Injury class 2 | Injury class 3 | Injury class 4 |
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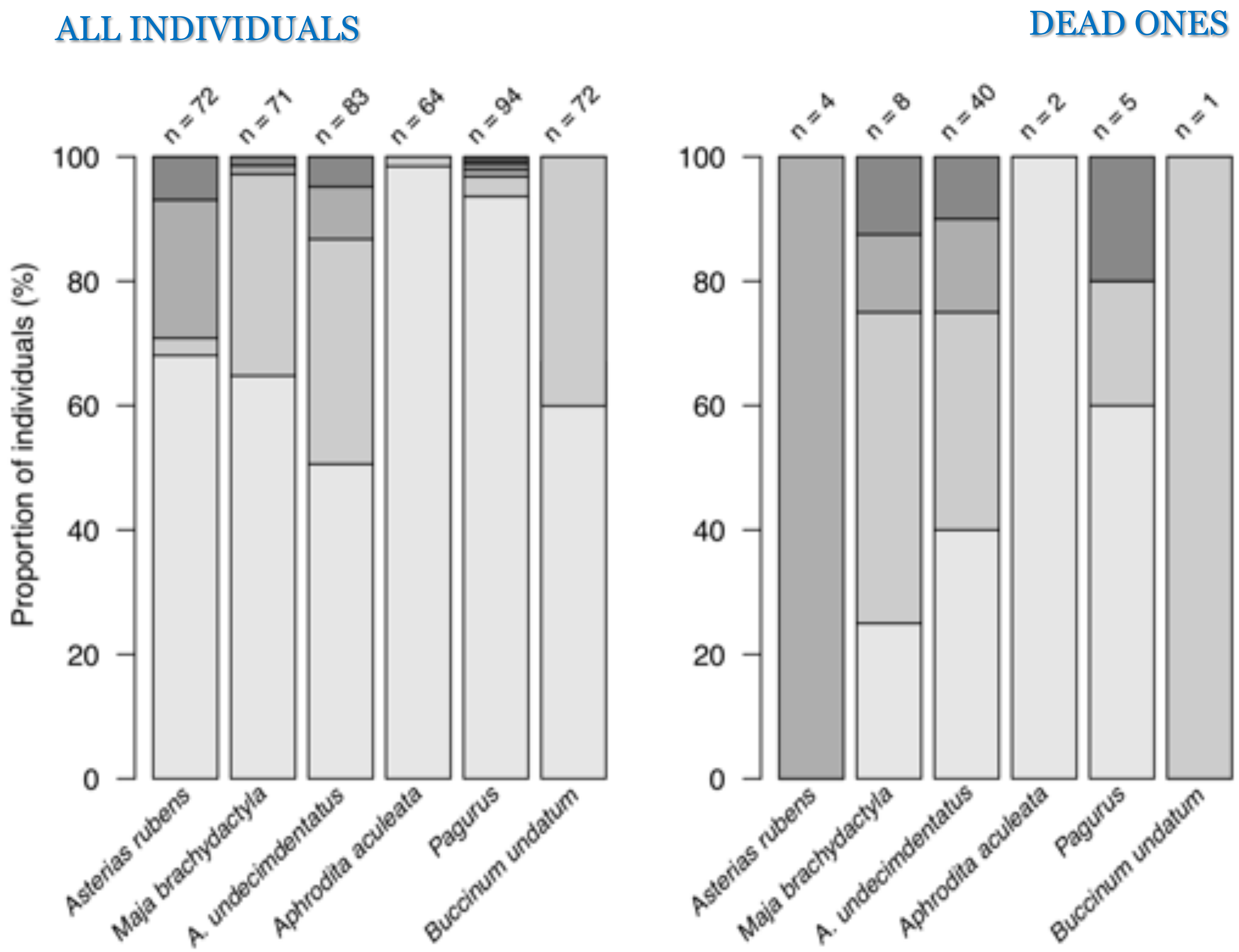


- Very different proportions depending on status (dead/alive)
- Survival seem to depend on injury classes

## SURVIVAL DEPENDING ON INJURY CLASSES

$$S'(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1 - \pi)$$

MIXTURE

$\pi, \alpha, \gamma$

Maximization of model likelihood,
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$$S'(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1 - \pi)$$

MIXTURE

Injury class → $\pi, \alpha, \gamma$

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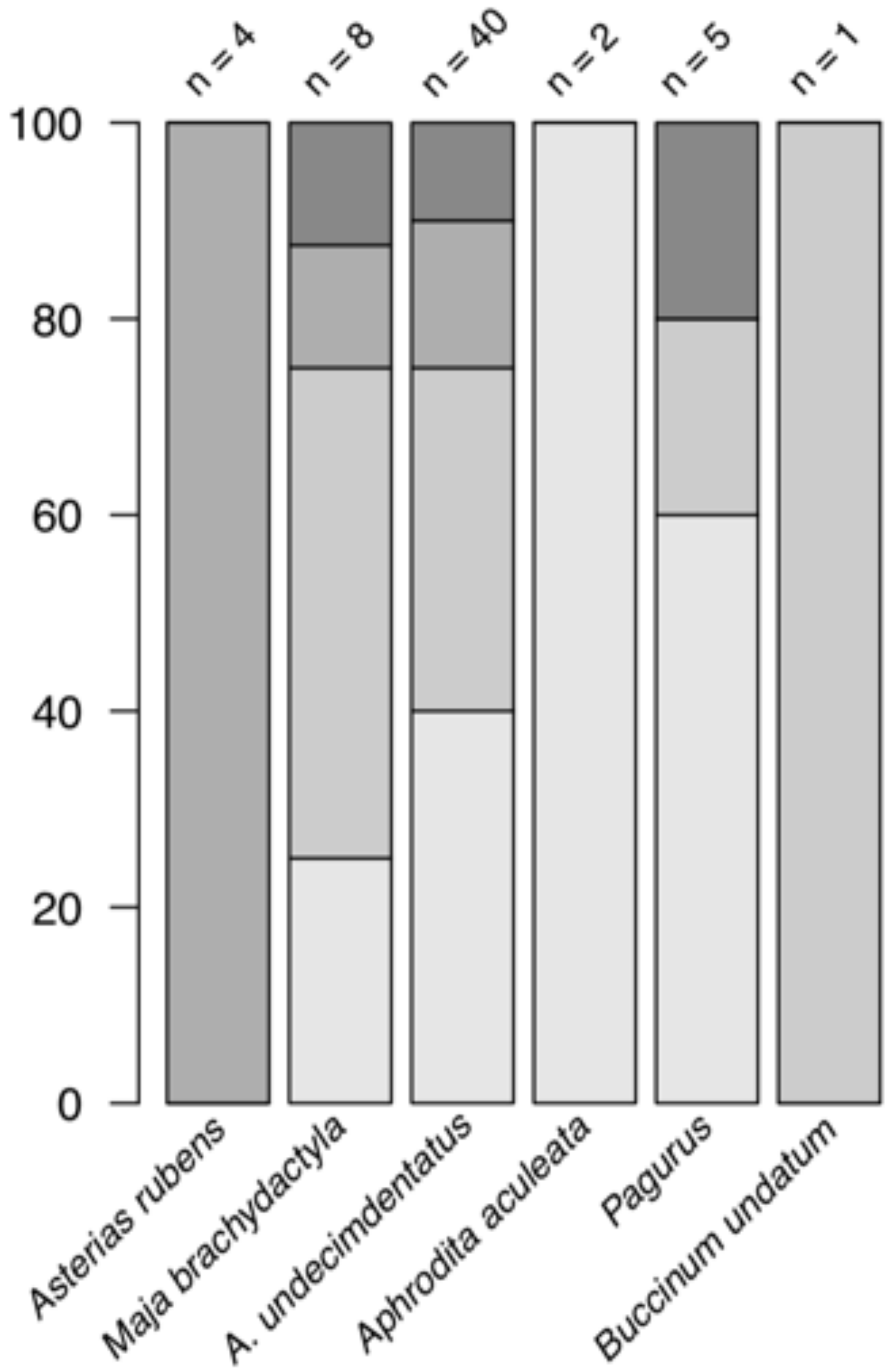

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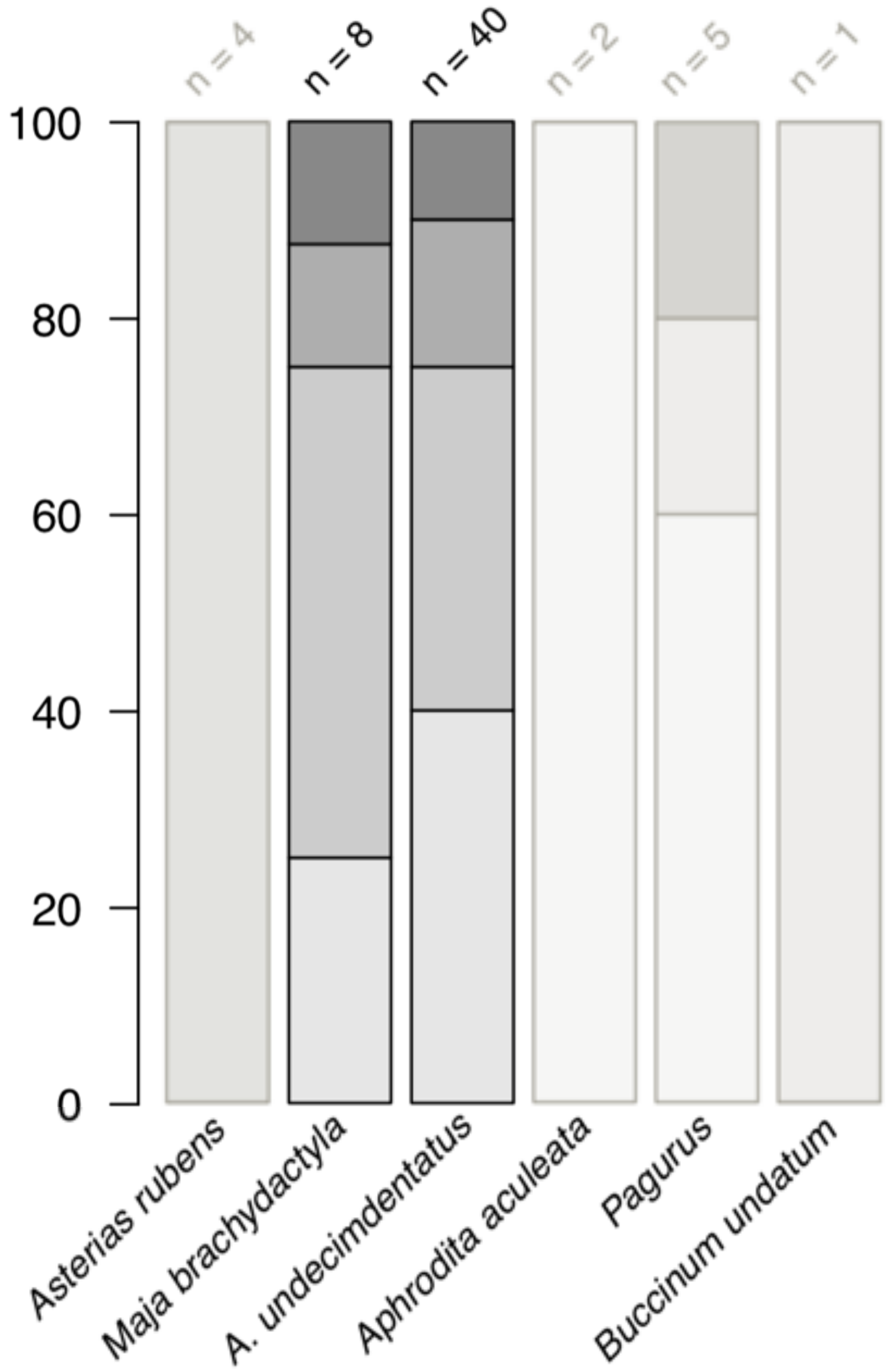

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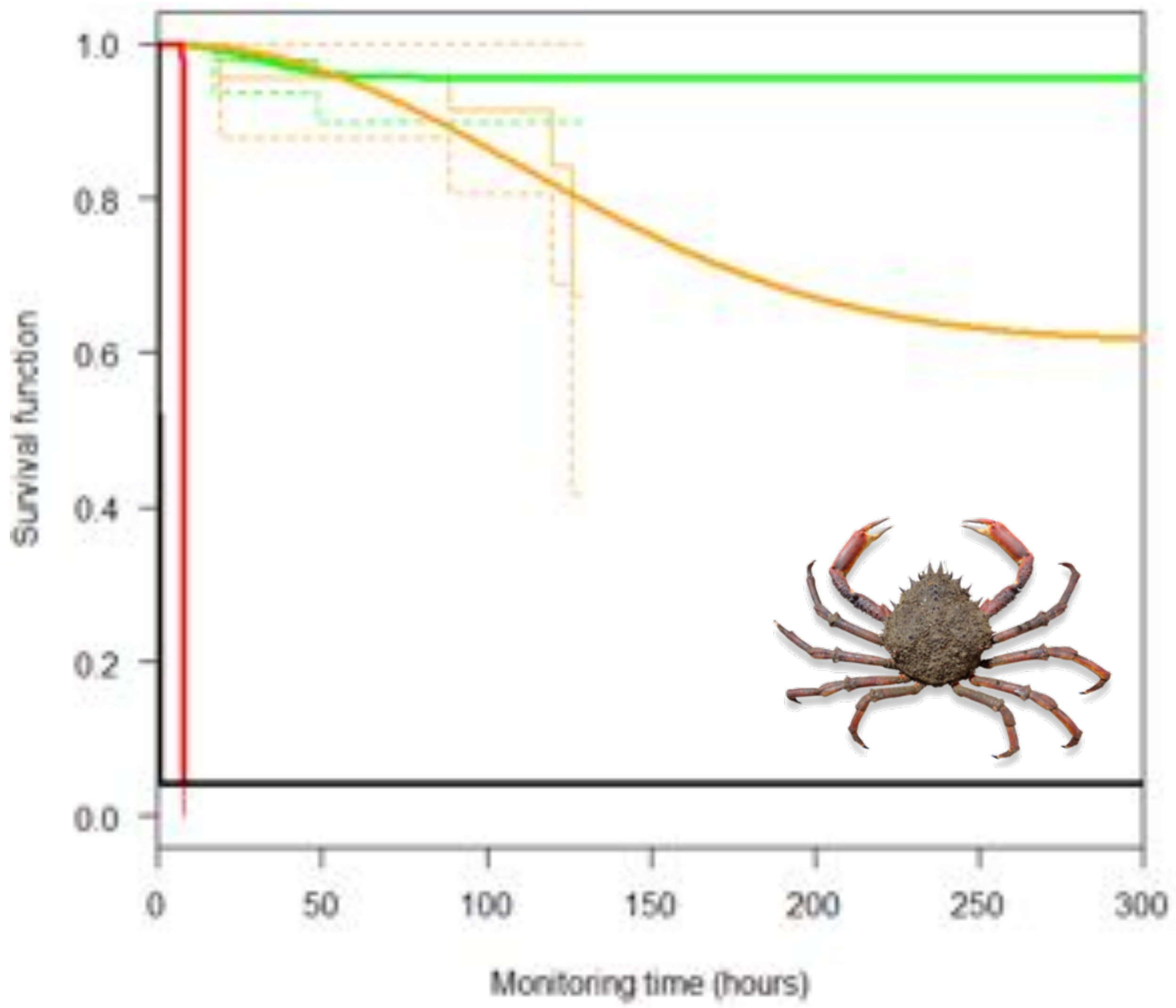
*Maja brachydactyla*




Injury class 1
(no damage)

Injury class 2
(missing legs)

Injury class 3
(carapace cracks)

Injury class 4
(crushed)

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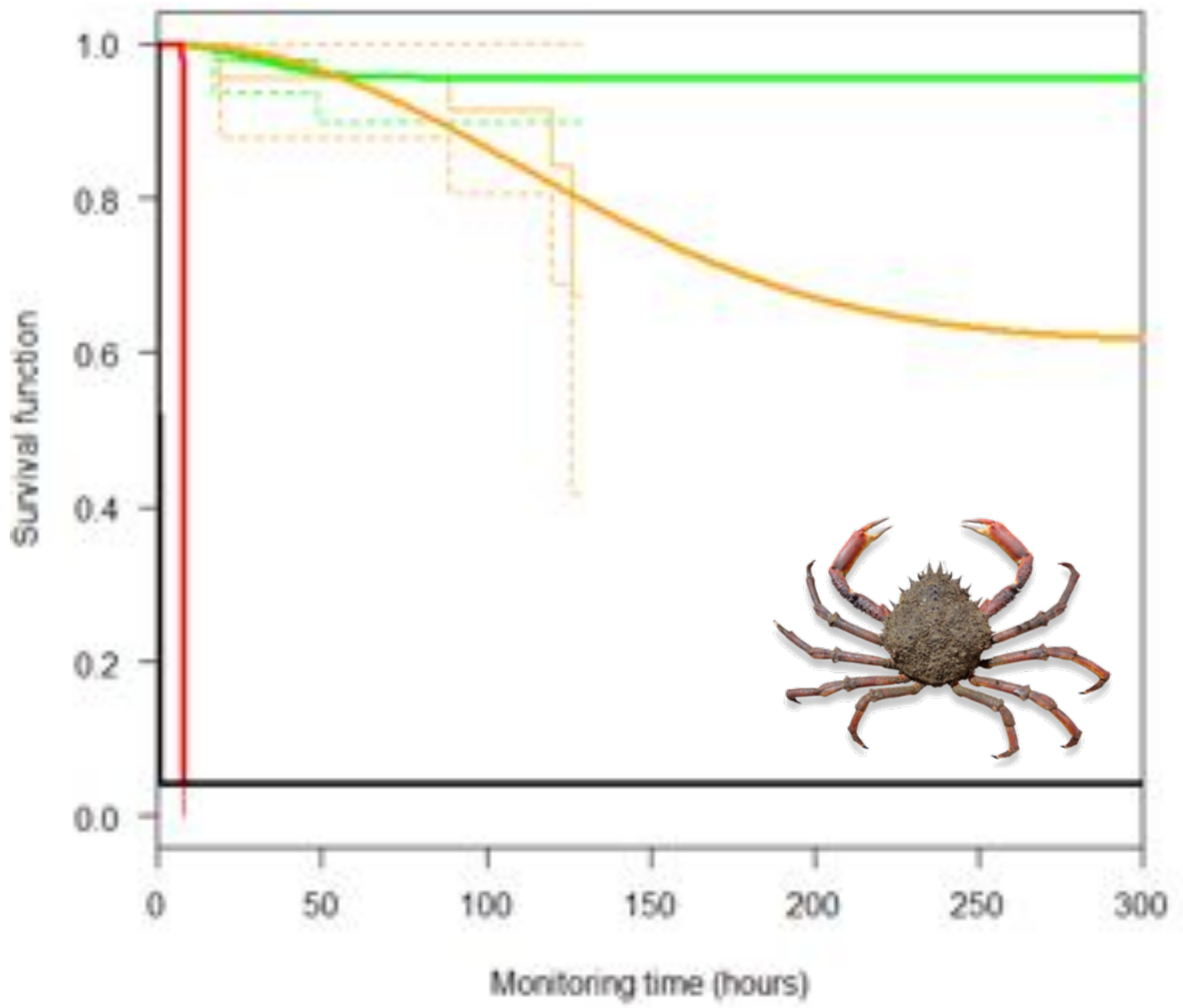


Injury class 1 (no damage) — $SMM \Rightarrow \pi = 96\%$

Injury class 2 (missing legs) — $SMM \Rightarrow \pi = 61\%$

Injury class 3 (carapace cracks) — $SMM \Rightarrow \pi \approx 0$

Injury class 4 (crushed) — $SMM \Rightarrow \pi \approx 0$

## SURVIVAL DEPENDING ON INJURY CLASSES

$$S'(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1 - \pi)$$

MIXTURE

Injury class → $\pi, \alpha, \gamma$

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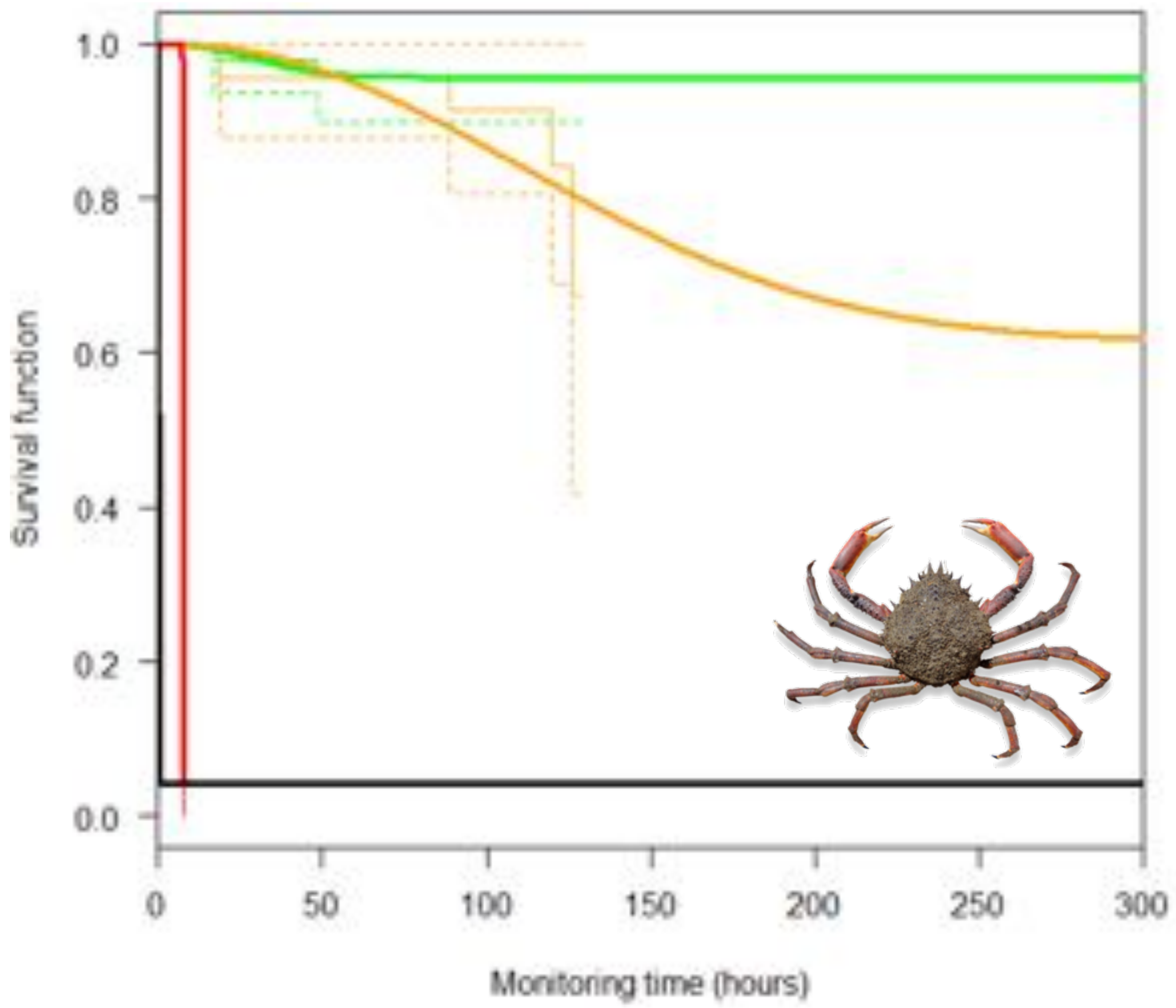
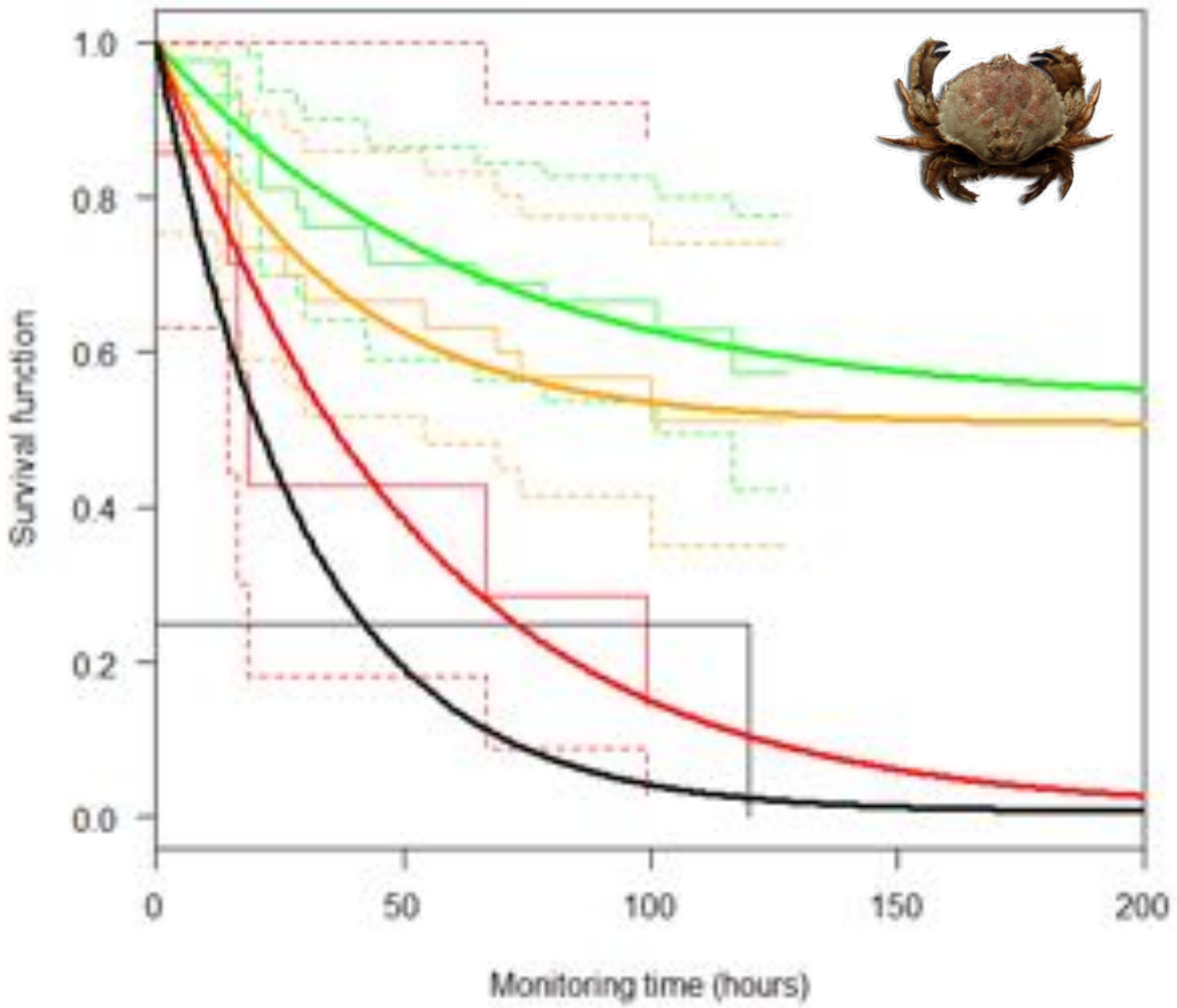
quasi-Newton optimisation algorithm (*optim*)

*Maja brachydactyla*




*Atelecyclus undecimdentatus*



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Mixed-Effects Cox Proportional Hazard Models
(multivariate and backward selection of variables)

- *Maja brachydactyla*

  - Injury // exp (coef) 12.2 / S.E. (coef) 0.78 / $p = 0.0014$
  - $V_{capture}$ // exp (coef) 0.25 / S.E. (coef) 0.6 / $p = 0.02$

- *Atelecyclus undecimdentatus*

  - Injury // exp (coef) 1.95 / S.E. (coef) 0.18 / $p < 0.001$
  - Air exposure // exp (coef) 1.06 / S.E. (coef) 0.03 / $p = 0.06$

## CONCLUSION

- Very high survival (> 90%) for :
  - *Asterias rubens*
  - *Aphrodita aculeata*
  - *Buccinum undatum*
  - *Pagurus*

- In line with other studies :
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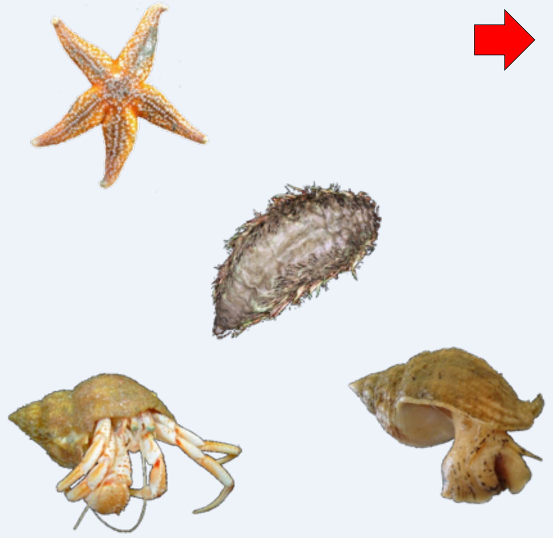

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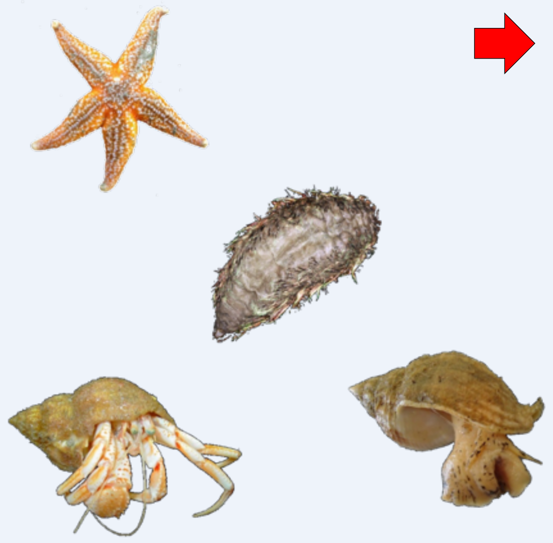

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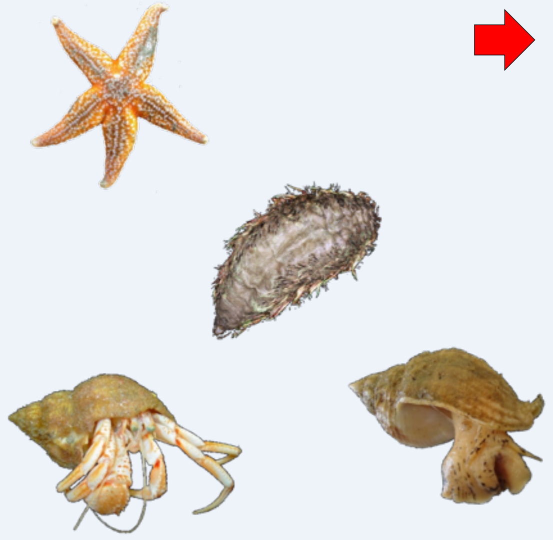

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- Beyond this work
  - Understand the fate of dead discards
  - Video, and trophic interactions (DNA metabarcoding, isotopy)

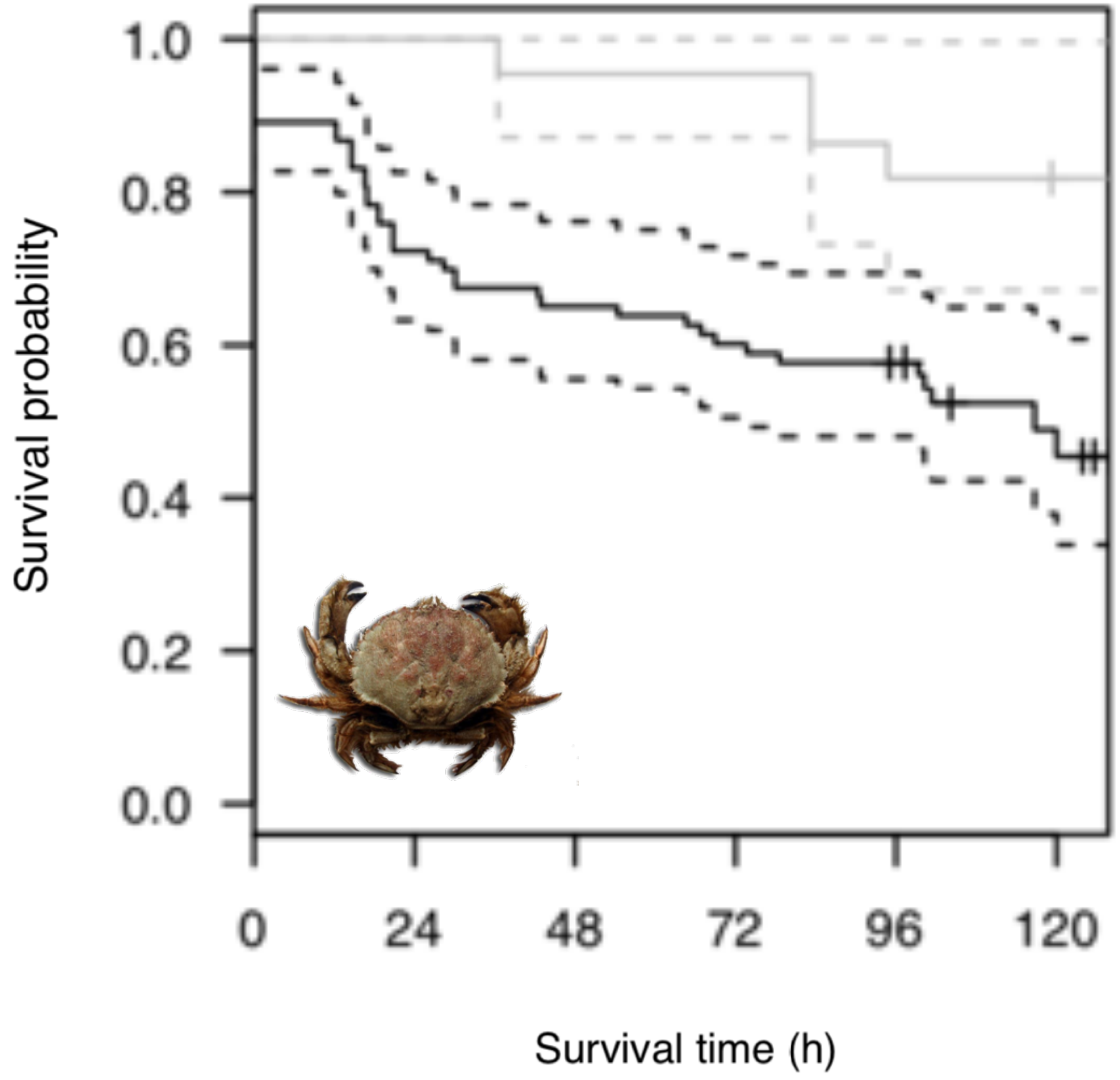
**MERCI !!!**

*IFREMER – Sonia Méhault*

# SURVIVAL AT THE END OF THE EXPERIMENT

| | $n_{total}$ ($n_{dead}$) | $n_{control}$ ($n_{dead}$) | Survival index (%) | Predicted survival (%) |
|---|---|---|---|---|
| *Asterias rubens* | 72 (4) | 19 (1) | 94.4 | 93.8 |
| *Maja brachydactyla* | 71 (8) | 18 (1) | 88.7 | SMM + Injury |
| *A. undecimdentatus* | 83 (40) | 22 (6) | 51.8 | 47.2 |
| *Aphrodita aculeata* | 64 (2) | 4 (0) | 96.9 | - |
| *Pagurus* | 94 (5) | 62 (2) | 94.7 | 93.4 |
| *Buccinum undatum* | 72 (1) | 19 (2) | 98.6 | - |

## SURVIVAL CURVES (KAPLAN-MEIER)




** *survdiff* (log-rank test)

CIEM

Workshop on Methods for Estimating Discard Survival (WKMEDS), 2014