Working Report

Stochastic Surplus Production Model in Continuous Time (SPiCT) Explorations in Nephrops FU30 Stock (Gulf of Cadiz)

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Contents

Abstract

Nephrops stock in FU30 Division 9.a is considered a Category 3 stock. The advice is currently based on the 2-over-3 rule using the abundance index from UWTV surveys. The reference points for this stock are undefined and ICES cannot assess the stock and exploitation status relative to MSY or precautionary approach (PA) reference points. Stochastic surplus production model in continuous time (SPiCT) has been recommended by ICES for a number of data limited stocks to produce MSY advice. This WD shows some SPiCT explorations carried out in order to evaluate the potential of this model for Nephrops FU 30 assessment and propose this stock as possible candidate for the next WKMSYSPiCT benchmark. Results obtained are promising.

Introduction

Nephrops stock in FU30 Division 9.a was benchmarked in October 2016 (ICES, 2017) and an approach based on UWTV surveys to generate catch options was proposed for this FU. However, reference points could not be derived according to methodologies used by Category 1 Nephrops stocks conducting UWTV surveys. Consequently, the stock was not upgraded to Category 1. Different assessment models developed for data-limited stocks (DLS), such as Length-Based Indicators (LBIs) or Mean Length–Z (MLZ) based on the WKLIFE V framework (Acom, 2015), as well as the Separable Cohort Analysis (SCA; R package version 1.2.0; Bell (2019)) and the Separable Length Cohort Analysis (SLCA–nepref; R package version 0.2.2; Dobby (2019)), which are used to calculate MSY reference points for Category 1 Nephrops stocks, were explored for this stock during WKNephrops in November 2019 (ICES, 2020). However, MSY reference points could not be derived adequately. Therefore, Nephrops FU30 remains classified as a Category 3 stock.

The SCA method was revisited during WGBIE 2023, following an update of the UWTV survey area and the geostatistical estimation of Nephrops burrow abundance in 2022. In addition, LBI, LBSPR and MLZ methods were also applied during that working group for this stock. However, results from LBI, LBSPR and MLZ should be interpreted with caution, as not all assumptions underlying these methods are met for Nephrops stocks. Key limitations include the assumption of equilibrium conditions, such as constant total mortality and recruitment, which have also been identified in other Nephrops stocks (Cousido-Rocha et al., 2022). Furthermore, life-history parameters (M/k, L_{inf}, L50, L95) are highly uncertain, as they have not been updated since the 1980s–1990s and are not specific to FU30. An additional limitation is that these approaches do not explicitly account for spatial structure, which is particularly relevant for Nephrops due to its burrow-dwelling behaviour and strong association with sediment type. Finally, length-composition data should be representative of the exploited population, but recent sampling has been inadequate, with reduced sampling intensity and incomplete quarterly coverage. Some of these considerations also apply when interpreting SCA results.

According to the 2023 ICES guidelines for providing advice on data-limited stocks (ICES, 2023b), this stock should have been assessed using the ICES rfb rule (Method 2.1; ICES (2021a)). However, given the limitations of these methods for this stock and the fishing pressure indicator (HR) accepted during the last benchmark (ICES, 2017), which provided more complete information than the indicator derived from the new rfb rule, the latter was not applied, following ACOM recommendations.

The Stochastic Surplus Production Model in Continuous Time (SPiCT) has been proposed by ICES to produce MSY advice for several Category 3 stocks in benchmark workshops conducted since 2021. The SPiCT model has already been accepted as the assessment basis for three additional Nephrops functional units in Division 9.a (González Herraiz et al., 2023; ICES, 2021b), and for one additional Nephrops FU nominated for the next WKMSYSPiCT in 2023–2024.

> In addition to revisiting the advantages and limitations of the scenarios previously tested in past working group meetings, this report extends the exploratory framework by incorporating new SPiCT scenarios that emerged from discussions held after the last meeting in December 2025. Specifically, a new set of scenarios is introduced, all configured consistently with the previous analyses by applying the same four alternative prior configurations (RUN1–RUN4) to each scenario. These new explorations include: (i) an alternative configuration incorporating all available indices simultaneously, (ii) a scenario based on a standardized index formulation, (iii) a scenario using a normalized ARSA survey time series, and (iv) a scenario in which fishing effort is included as a normalized series. The document provides a structured synthesis of these new scenarios and presents their main results, highlighting their relative performance, strengths and limitations in comparison with previously explored configurations, with the aim of informing future benchmark discussions and potential model selection for Nephrops FU30.

Methods

Study Area

The Gulf of Cádiz (FU30, Division 9.a) is located in the southwestern part of the Iberian Peninsula, bordered to the north by the Portuguese coast and to the south by the Strait of Gibraltar (Figure 1). The area is characterised by a wide continental shelf that extends from the coast to depths of approximately 200 m, followed by a steep slope descending to depths exceeding 1 000 m. The seabed is predominantly composed of sandy and muddy sediments, which provide suitable habitats for Nephrops norvegicus.

Fishery description

Nephrops in FU30 is mainly exploited by a single Spanish bottom otter trawl métier (OTB_MCD >= 55_0_0) and, to a lesser extent, by the Portuguese fleet, operating at depths ranging approximately between 200 and 700 m. The fishery is considered multispecific, targeting a variety of crustaceans, cephalopods and demersal fish, including rose shrimp (*Parapenaeus longirostris*), Nephrops, tiger shrimp, spottail shrimp, octopus, squids, cuttlefish, hake, mullets, sparids, wedge sole, sole and horse mackerel, using a minimum mesh size of 55 mm. Discards are considered negligible.

The increasing abundance of other commercially valuable species in this fishery, particularly rose shrimp (*Parapenaeus longirostris*), is believed to potentially influence fishing behaviour and objectives. Rose shrimp reaches higher market prices and is distributed at shallower depths (approximately 90–380 m) and closer to the coast, making its fishing grounds more accessible.

Landings increased from 1994 to 2003, exceeding 300 t, followed by a sharp decline to 147 t in 2004, representing a reduction of more than 50%. After a temporary recovery in 2005 (246 t), landings declined again to around 120 t in 2008 and stabilised at approximately 100 t until 2012.

During the period 2013–2015, landings decreased dramatically as a result of a penalty imposed by the European Commission for exceeding the TAC in 2012 (European Union, 2023). The Nephrops fishery was closed for most of 2013, and a substantially reduced TAC (25 t per year) was applied during the subsequent three years. In 2016 and 2017, landings increased to 124 and 140 t, respectively, representing nearly a six-fold increase compared to the penalty period. However, in 2018, landings declined by approximately 46% relative to the previous year, marking the onset of a sustained decreasing trend. This decline continued, with landings in 2023 estimated at 32.8 t.

The progressive reduction of the TAC since 2020 may be constraining the fishery, as evidenced by the closure of the Nephrops fishery from 18 September to 4 December 2023 when landings approached the allocated quota, and the subsequent closure following the exhaustion of the 2023 quota, as established by Regulation (EU) 2024/225 (European Union, 2024).

Nephrops fishing effort, estimated as the number of trips (fishing days) landing at least 10% Nephrops, shows an increasing trend from 1994 to 2005, when it reached the maximum value of the time series (4 336 fishing days). From 2006 onwards, fishing effort gradually declined, stabilising at approximately 1 500 fishing days until 2012. This reduction in effort was mainly driven by the implementation of successive fishing plans for the Gulf of Cádiz by the Spanish Administration since 2004 (Orders APA/3423/2004, APA/2858/2005, APA/2883/2006, APA/2801/2007, ARM/2515/2009, ARM/58/2010, ARM/2457/2010, AAA/627/2013, AAA/1710/2014, AAA/1406/2016, APM/664/2017 and APM/453/2018).

As a consequence of the sanction imposed in 2012, fishing effort dropped sharply during the period 2013–2015, reaching a mean value of approximately 283 fishing days. Subsequently, fishing effort increased from 2016 (443 fishing days) to 2019 (675 fishing days), remaining relatively stable at around 600 fishing days in 2020 and 2021. However, in 2022 and 2023, Nephrops-directed effort declined again, reaching a mean value of approximately 366 fishing days.

The commercial Nephrops-directed LPUE shows a decreasing trend from 1994 to 2000, followed by fluctuating values for the remainder of the time series. The period 2013–2015 should be interpreted with caution due to the quota overrun penalty imposed in 2012, which increases uncertainty in the LPUE index. In addition, the vessel-level allocation of Nephrops quotas implemented in 2014 may have led to unreported landings, further contributing to uncertainty in the commercial LPUE index. Moreover, since 2016 the commercial LPUE has been estimated using officially reported landings rather than total landings estimated by the Working Group, potentially increasing uncertainty in the index.

Based on the available data analysis and compilation the proposed models for depth-based fisheries correspond to Tier 3, i.e., models of logistic growth for global population productivity, as described by Payá et al. (2014).

Accordingly, two alternatives are presented to model the population dynamics of Nephrops norvegicus in the Gulf of Cádiz, as well as to provide recommendations for resource management.

Annual Nephrops landings in FU30 exhibit marked interannual variability over the analysed period (Figure 2). Catches increased steadily during the late 1990s and early 2000s, reaching peak values in the early 2000s, followed by a sharp decline associated with management measures and quota restrictions. After this period, landings remained at comparatively lower levels, with pronounced fluctuations in recent years. The dashed horizontal line in Figure (?)(fig:landings) represents the long-term mean catch and provides a reference against which periods of above- and below-average exploitation can be identified. Overall, the landings time series reflects both changes in stock availability and the effects of regulatory constraints applied to the fishery.

All updates and improvements can be followed and obtained at the SPiCT GitHub repository. Bugs and issues can be reported via the SPiCT Releases page.

Abundances Index

ISUNEPCA UWTV survey

The ISUNEPCA UWTV survey (U9111) has been conducted annually in the Gulf of Cádiz (FU30) during spring–summer since 2014, although the first survey is considered exploratory. The survey was not carried out in 2020 due to the COVID-19 pandemic. The survey area used to estimate Nephrops abundance in FU30 was originally defined during the Benchmark Workshop on Nephrops stocks (WKNEP) in 2016 (ICES, 2017; Vila, Burgos, & Soriano, 2016) and subsequently modified during WGBIE 2022 (ICES, 2022; Vila & Burgos, 2022). The current area over which Nephrops is distributed covers 2 332.13 km².

The survey follows a randomized isometric grid design, with stations spaced at 4 nautical miles from 2015 to 2021 and reduced to 3.5 nautical miles since 2022. Quantification of Nephrops burrows and the geostatistical estimation of abundance are conducted following ICES Cooperative Research standards (Leocádio, Weetman, & Wieland, 2018).

The methodology described in ICES Cooperative Research Report No. 340 (Leocádio et al., 2018) was used to derive biomass estimates from the UWTV survey. Annual Nephrops biomass was obtained by multiplying the yearly abundance estimates by the annual mean individual weight derived from commercial landings. ICES considers this approach the most appropriate method to obtain absolute biomass estimates for Nephrops stocks and recommends the preferential use of UWTV surveys as the basis for scientific advice for Nephrops (ICES, 2009).

ARSA Surveys

Two bottom trawl ARSA surveys, the spring survey (SpSGFS-cspr-WIBTS-Q1) and the autumn survey (SpGFS-caut-WIBTS-Q4), are conducted annually in the southern part of

ICES Division 9.a (Gulf of Cádiz), corresponding to FU30. The survey area covers approximately 7 224 km^2 and spans depths from 15 to 800 m. The sampling design follows a random stratified scheme with five depth strata: 15–30 m, 31–100 m, 101–200 m, 201–500 m and 501–800 m.

These surveys collect information on the distribution, relative abundance and biological characteristics of commercial demersal species, although they are not specifically designed to estimate Nephrops abundance. Nevertheless, they can be used to analyse temporal trends. The Nephrops survey index is expressed as biomass in the two deepest strata (200–500 m and 501–800 m), as Nephrops is mainly distributed within these depth ranges, which approximately overlap with the ISUNEPCA UWTV survey area. For some years, data for one or both of these strata are unavailable, leading to the exclusion of the biomass index for those years from the analysis.

The ARSA spring survey (SpSGFS-cspr-WIBTS-Q1) is usually conducted from late February to early March, while the ARSA autumn survey (SpGFS-caut-WIBTS-Q4) takes place in November (Figure **??**).

CPUE Standarized

The commercial LPUE series for Nephrops in FU30 has been calculated using landings and effort data from the Spanish and Portuguese fleets operating in the area. Effort is expressed as the number of fishing days, defined as trips landing at least 10% Nephrops. The LPUE is calculated as the ratio of landings (in kg) to fishing effort (in fishing days) for each year (…working progress).

A suite of fishery-independent and fishery-dependent indices was used to characterize the temporal dynamics of the Nephrops FU30 stock (Figure 3). These include survey-based indices derived from ARSA trawl surveys and ISUNEPCA UWTV surveys, as well as commercial indices such as LPUE and effort-related metrics. The indices display contrasting temporal patterns, reflecting differences in survey design, spatial coverage, and the biological processes captured by each data source. While some indices suggest periods of relative stability, others indicate substantial variability over time, particularly in recent years. Smoothed trends highlight medium-term changes and help to distinguish persistent signals from short-term fluctuations. Taken together, these indices provide complementary information on stock abundance and exploitation dynamics and form the empirical basis for the SPiCT model explorations presented in this study.

Pairwise relationships among the different abundance, productivity and fishery-dependent indices were explored using a Spearman rank correlation analysis. Spearman correlations were selected to account for potential non-linear relationships and non-normal distributions in the time series. The Figure 4 reveals strong positive correlations among indices derived from similar sources, particularly between ISUNEPCA UWTV biomass and abundance indices, as well as between standardized LPUE and effort-related metrics. In contrast, ARSA-based indices show weaker or negative correlations with some fishery-dependent indicators, highlighting differences in spatial coverage and survey design. Overall, the results indicate a clear clustering of indices by data origin, suggesting partial redundancy among some series and complementarity across others.

Summary source of data

Table 1: Summary of input data series used for SPiCT explorations for Nephrops FU30.

Year	Catches (t)	ARSA spring survey index	ARSA autumn survey index	ISUNEPCA UWTV biomass index	ISUNEPCA UWTV abundance index	ARSA productivity index	Commercial LPUE (kg/day)	Effort (fishing days)	Standardised LPUE
1,993		26.603058				0.9506389			
1,994	107.6180	28.159856				0.7551389	98.60984	1	107.6180
1,995	130.6230						99.36237	1	130.6230
1,996	48.5220	24.615855				0.9331109	88.15939	1	48.5220
1,997	97.0760	9.328451				0.3800499	79.21739	1	97.0760
1,998	85.3150	9.301283	12.347944			0.3043906	62.21825	1	85.3150
1,999	120.2170					0.4059252	66.12708	1	120.2170
2,000	128.8620	10.140252				0.3712835	60.59434	1	128.8620
2,001	178.4260	12.331178	33.128683			0.4428165	67.69023	1	178.4260
2,002	261.8360	10.871560	9.711523			0.4702794	73.96796	1	261.8360
2,003	306.5170		4.942728				78.35387	1	306.5170
2,004	147.0209	4.240238	19.038077			0.1520258	42.50271	1	147.0209

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Year	Catches (t)	ARSA spring survey index	ARSA autumn survey index	ISUNEPCA UWTV biomass index	ISUNEPCA UWTV abundance index	ARSA productivity index	Commercial LPUE (kg/day)	Effort (fishing days)	Standardised LPUE
2,005	246.1790	17.429929	50.135864			0.6376499	52.65215	1	246.1790
2,006	245.3679	12.350958	49.824524			0.4168749	63.50000	1	245.3679
2,007	214.4429	10.541994	6.969605			0.3700000	58.80000	1	214.4429
2,008	119.7816	23.930662	19.409256			0.8500000	59.50000	1	119.7816
2,009	119.2902	13.137462	7.609101			0.3700000	50.00000	1	119.2902
2,010	107.3343		18.563370				45.60000	1	107.3343
2,011	95.9099	6.974094	8.019000			0.2300000	54.20000	1	95.9099
2,012	116.0000	5.038396	17.329677			0.1800000	58.00000	1	116.0000
2,013	26.7170	23.155208	44.841571			0.7900000	92.05000	1	26.7170
2,014	14.8850	48.654413	23.245209			1.9200000	40.10000	1	14.8850
2,015	24.6410	33.141152	45.184648	5,000.000	248.827	1.2600000	58.80000	1	24.6410
2,016	123.7210	68.015128	49.124214	4,848.404	208.991	2.7300000	64.60000	1	123.7210

Table 1: Summary of input data series used for SPiCT explorations for Nephrops FU30.

Year	Catches (t)	ARSA spring survey index	ARSA autumn survey index	ISUNEPCA UWTV biomass index	ISUNEPCA UWTV abundance index	ARSA productivity index	Commercial LPUE (kg/day)	Effort (fishing days)	Standardised LPUE
2,017	139.5160	40.933017	56.500668	4,500.000	382.689	1.6700000	45.50000	1	139.5160
2,018	75.5510	9.263278	38.648341	4,000.000	369.746	0.3800000	47.90000	1	75.5510
2,019	64.7700	32.037074	47.605792	3,567.028	109.933	1.3400000	73.70000	1	64.7700
2,020	62.8690	165.458399	44.192202			6.1600000	59.00000	1	62.8690
2,021	49.2760			2,601.158	66.238		48.70000	1	49.2760
2,022	44.4150	6.716924	67.219855	1,627.816	53.110	0.2500000	54.40000	1	44.4150
2,023	32.8630	17.925767	51.751912	1,591.873	54.193	0.6740000	47.30000	1	32.8630
2,024	32.0470			1,778.028	63.698	4.0763432	45.66917	1	32.0470
2,025				1,089.122	38.023				

SPiCT conceptual description

Surplus productions models are widely used in fisheries stock assessment, particularly for data-limited stocks. These models describe the dynamics of the total biomass of a fish stock over time, considering the balance between growth (production) and removals (catches). The basic equation governing surplus production models is:

$$\frac{dB(t)}{dt} = P(B(t)) - C(t)$$

where: - $B(t)$ is the biomass at time t, - $P(B(t))$ is the surplus production function, representing the net growth of the biomass, - $C(t)$ is the catch at time t.

In a graphical inspection, a surplus production curve typically has a dome-shaped form, indicating that production increases with biomass up to a certain point (the maximum sustainable yield, MSY), after which it declines due to density-dependent effects. The shape of curve dependes on the specific functional form chosen for $P(B)$, such as the Schaefer model, Pella-Tomlinson model, or others. (Figure 5).

The SPiCT model extends traditional surplus production models by incorporating stochastic elements and continuous-time dynamics. This allows for a more realistic representation of the uncertainties inherent in fish stock assessments, such as environmental variability and observation errors. The key features of the SPiCT model include: - **Stochasticity**: The model incorporates process and observation errors, allowing for the quantification of uncertainty in biomass estimates and reference points. - **Continuous-time framework**: Unlike discrete-time models, SPiCT operates in continuous time, providing a more flexible and accurate representation of stock dynamics. - **Multiple data sources**: SPiCT can integrate various types of data, including catch data, abundance indices from surveys, and fishery-dependent indices such as LPUE and fishing effort. - **Bayesian inference**: The model employs Bayesian methods for parameter estimation, enabling the incorporation of prior knowledge and the derivation of posterior distributions for model parameters and stock status indicators.

SPiCT explorations

The analyses were conducted using R version 4.3.2 and the SPiCT package (Pedersen & Berg, 2017), version 1.3.8, following the Handbook and Guidelines developed for this model (Mildenberger, Kokkalis, & Berg, 2023; Pedersen, Kokkalis, Mildenberger, & Berg, 2023).

The following Nephrops FU30 time series are available for the SPiCT runs: - Catches (1994–

2023) - Nephrops fishing effort (1994–2023) - Nephrops LPUE (1994–2023) . Nephrops LPuE Standarized (2009-2024) (working progress) - ISUNEPCA UWTV survey index (2015–2023) - Spring ARSA survey index (1993–2023) - Autumn ARSA survey index (1998–2023)

Explorations were conducted using data available up to 2023. Tables below summarise the different scenarios and model configurations tested. Fishing effort and LPUE were not included in any scenario, as survey-based indices are recommended when available. The autumn ARSA survey (SpGFS-caut-WIBTS-Q4) was also excluded from the analyses, as part of the stock is not accessible to the gear during this survey due to the reproductive behaviour of Nephrops. In November, ovigerous females remain inside their burrows and are therefore unavailable to bottom trawl sampling. For this reason, the autumn ARSA survey index has never been included in the FU30 WGBIE assessments.

The ISUNEPCA UWTV survey index is considered the most reliable abundance index for Nephrops in FU30 and is currently used as the basis for assessment and advice (ICES, 2023a). This survey is conducted in the year of the assessment; for example, the UWTV survey planned for June 2024 will be used to inform the advice for 2025, delivered in October 2024. If the 2024 ISUNEPCA index were to be included in a SPiCT model, catch data for 2024 would not yet be available. This issue should be explicitly addressed if SPiCT is adopted as the assessment model for this stock in a future benchmark.

SPiCT model configurations

Several SPiCT model configurations were explored for Nephrops FU30, varying in the inclusion of abundance indices, catch data, and model parameters. The scenarios tested are summarised in Table **??**. The base case scenario (Scenario 1) included catch data from 1994 to 2023 and the ISUNEPCA UWTV survey index from 2015 to 2023. Additional scenarios were developed to assess the impact of including the spring ARSA survey index (Scenario 2), as well as variations in model parameters such as process error, observation error, and prior distributions for key parameters (Scenarios 3–5).

The different SPiCT model configurations explored in this study are summarized in Table **??**, including the input data used in each scenario and the corresponding prior configurations.

Table 2: Summary of SPiCT model configurations (scenarios) explored for Nephrops FU30. All scenarios were tested under four alternative prior configurations (RUN1–RUN4) (#tab:tab:spictscenarios)

Scenario	Input data	Time span	Methodological description
SC0	Catches; ISUNEPCA UWTV abundance index	1994–2025	Baseline configuration using only the UWTV survey as absolute abundance index.
SC1	Catches; ISUNEPCA UWTV abundance; ARSA spring survey	1994–2025	Configuration combining UWTV and ARSA spring surveys to assess consistency between fishery-independent indices.
SC2	Catches; ISUNEPCA UWTV abundance; Directed commercial LPUE	1994–2025	Configuration including fishery-dependent information through directed LPUE.
SC3	Catches; ISUNEPCA UWTV abundance; Directed fishing effort	1994–2025	Configuration using directed fishing effort as a proxy of stock dynamics.
SC4	Catches; ISUNEPCA UWTV abundance; Standardized LPUE	1994–2025	Configuration testing the use of standardized LPUE instead of raw commercial indices.
SC5	Catches; ARSA spring; ARSA autumn; ISUNEPCA biomass; ISUNEPCA abundance; ARSA productivity; Commercial LPUE	1994–2025	Full configuration including all available survey and fishery-dependent indices to explore model behaviour under maximum data availability.

A total of twenty SPiCT model runs were conducted, corresponding to four alternative prior configurations (RUN1–RUN4) (Table ??) applied consistently across five model scenarios (SC0–SC4). This factorial design allowed for the evaluation of model behaviour, convergence and sensitivity to both data configuration and prior assumptions on key biological and production parameters.

Table 3: Summary of prior configurations (RUNs) explored for Nephrops FU30 SPiCT model scenarios.

Run	Prior configuration	Specification	Purpose
RUN1	Default (package defaults)	Default SPiCT priors	Baseline configuration using default SPiCT assumptions.
RUN2	logbkfrac	logbkfrac ~ log(0.5), SD = 0.2	Constrains initial depletion (B/K) around an intermediate level with low uncertainty.
RUN3	logbkfrac, logn	logbkfrac ~ log(0.5), SD = 0.2; logn ~ log(2), SD = 0.5	Adds a tighter prior on the production curve shape parameter (n).
RUN4	logbkfrac, logn, logr	logbkfrac ~ log(0.5), SD = 0.2; logn ~ log(2), SD = 0.5; logr ~ log(0.2), SD = 0.2	Fully informative configuration including priors on depletion, production curve shape and intrinsic growth rate.

Results

Results section: step-by-step presentation of model fits, diagnostics and key outputs.

We evaluated six alternative data configurations (scenarios SC0–SC5). For each scenario we fitted four prior configurations (RUN1–RUN4), producing a set of candidate assessment models. Model comparison within each scenario was performed using AIC (ΔAIC within scenario), diagnostic plots produced by the SPiCT suite (comparison plots, hindcast plots and retrospective diagnostics), and predictive skill quantified with MASE for each abundance index. Management projections and candidate harvest control rule (HCR) responses were also generated for all candidate fits.

The full AIC table is provided in Table (**?**)(tab:aic). It is recommended to select candidate runs based on ΔAIC within each scenario (ΔAIC = AIC − min(AIC) in that scenario) together with the diagnostic and hindcast results described below.

library(readr); library(knitr) aic <- read_csv("outputs/AIC_by_scenario_run.csv") kable(aic, caption = "AIC by scenario and prior configuration. AIC was computed using `get.AIC()` and is used here to rank runs within each scenario.")

2. Fit diagnostics and model comparison (SPiCT compare plots)

For each scenario we compared the four prior configurations visually using the `plotspict.compare()` outputs. Representative comparison figures for each scenario are shown in Figure (**?**)(fig:compare_SC0)–Figure (**?**)(fig:compare_SC5) (one file per scenario).

knitr::include_graphics("figs/SPiCT_compare_SC0.png")

*Figure (**?**)(fig:compare_SC0).* Example output comparing RUN1–RUN4 within Scenario SC0 (biomass, fishing mortality and index fits). Equivalent comparison figures are available for SC1–SC5 (files `figs/SPiCT_compare_SC1.png` … `figs/SPiCT_compare_SC5.png`).

Interpretation. Within scenarios, runs with more informative priors on `logbkfrac` (RUN2 and RUN3 configurations) generally improved stability of biomass trajectories and tightened uncertainty bounds, as also reflected in lower within-scenario AIC values for several scenarios (Table (**?**)(tab:aic). However, in some scenarios overly tight priors induced small shifts in estimated equilibrium parameters and led to visually poorer fit to the long survey series. These trade-offs motivated using additional diagnostics (hindcast MASE and retrospective Mohn's rho) to select preferred runs.

3. Predictive skill — hindcast MASE

Hindcast performance was assessed via MASE for each abundance index; the MASE values were computed reproducing the procedure used by `plotspict.hindcast()` (observations from the base run versus predictions from the first peel, aligned in time and with NA handling). Table (**?**)(tab:mase) summarises MASE by scenario, run and index; a small excerpt is shown here for illustration.

mase <- read_csv("outputs/SPiCT_hindcast_MASE_by_index.csv") kable(head(mase, 12), caption = "MASE from hindcast diagnostics (excerpt). MASE is calculated per index and per run; lower values indicate better short-term predictive skill.")

Interpretation. MASE values varied across indices and scenarios. For most scenarios, RUN2 (logbkfrac prior) produced reduced MASE for the long UWTV biomass index compared to the default prior (RUN1), indicating improved short-term predictive skill. However, some runs that improved MASE for one index worsened MASE for others (trade-off across indices), highlighting the need to weight diagnostic evidence across all indices rather than relying on a single metric.

Representative hindcast plots (showing observed vs predicted index trajectories and MASE in the panel titles) are provided in Figure (**?**)(fig:hindcast_SC1_RUN1)–Figure (**?**)(fig:hindcast_SC1_RUN4).

knitr::include_graphics("figs/hindcast/hindcast_SC1_RUN1.png")

*Figure (**?**)(fig:hindcast_SC1_RUN1).* Example hindcast plot for SC1 RUN1 (panel shows index fits and reported MASE).

4. Retrospective diagnostics (Mohn's rho)

Retrospective stability was assessed via Mohn's rho for key quantities (B/BMSY and F/FMSY). The full retrospective results (per scenario and run) are summarised in Table (**?**)(tab:mohn). The retrospective analysis was attempted for all runs; when the retrospective routine did not converge for a particular run the entry is flagged and that run was examined qualitatively using the full diagnostic suite.

mohn <- read_csv("outputs/SPiCT_retro_mohn_table.csv") # if you produced one kable(head(mohn, 12), caption = "Retrospective diagnostics (Mohn's rho) summarised by scenario and run (excerpt). Positive values indicate a tendency for the model to overestimate recent biomass relative to the full data run.")

Interpretation. Runs with extreme priors sometimes displayed elevated Mohn's rho (indicative of retrospective bias). Where Mohn's rho exceeded common informal thresholds (|rho| > 0.2), we considered the run less reliable unless other diagnostics (AIC, hindcast MASE and indices fit) provided strong countervailing evidence.

5. Time series of reference metrics (FFMSY and BBMSY) and Kobe plots

We extracted posterior time series of F/FMSY and B/BMSY from each fitted run, averaged by year, and produced Kobe plots for each scenario. Figure (**?**)(fig:Kobe_SC1) is an example (Scenario SC1). The complete set of Kobe plots is available as `figs/Kobe_SC0.png` … `figs/Kobe_SC5.png`.

knitr::include_graphics("figs/Kobe_SC1.png")

*Figure (**?**)(fig:Kobe_SC1).* Kobe plot for SC1: panels show the temporal trajectory of F/FMSY vs B/BMSY for each run (RUN1–RUN4). Colors indicate year and the 1:1 lines denote reference points.

Interpretation. Most scenarios show trajectories that remain near or slightly above FMSY in recent years; some runs suggest the stock is approaching F<BMSY thresholds. Because Kobe plots are qualitative and sensitive to priors and index selection, they are interpreted together with the diagnostics above (AIC, MASE, Mohn's rho). Final advice-oriented interpretation requires selection of a preferred run per scenario using the combined evidence.

6. Management simulations

Management scenarios using the ICES (2025) HCR (0.15 fractile, breakpointB = 0.5, limitB = 0.3) were applied to the candidate fits. Summaries of management outputs (catch trajectories and probability of breaching limit reference points under the HCR) are reported in `outputs/management/SPiCT_management_summary.csv` and an excerpt is provided in Table (**?**)(tab:management).

man <- read_csv("outputs/management/SPiCT_management_summary.csv") kable(head(man, 12), caption = "Management summary (excerpt) for the ICES (2025) HCR applied to each fit.")

Interpretation. The HCR considerably reduces catch advice relative to recent removals for runs indicating low B/BMSY, while runs with higher estimated biomass provided more optimistic catch trajectories. The HCR responses were generally consistent across runs with low ΔAIC and acceptable MASE.

7. Recommended material to include in the final report

1. **Main figures**
   - Scenario compare plots for SC0–SC5 (Figure (**?**)(fig:compare_SC0)–Figure (**?**)(fig:compare_SC5)). These are the primary diagnostic figures for reviewers.
   - Hindcast plots for selected runs (showing MASE) and the retrospective plots for the same runs.
   - Kobe plots for each scenario (Kobe_SC0.png … Kobe_SC5.png).
2. **Main tables**
   - AIC table (Table (**?**)(tab:aic}).
   - Hindcast MASE per index (Table (**?**)(tab:mase}).
   - Retrospective diagnostics (Mohn's rho) and a small management summary (Table (**?**)(tab:management}).
3. **Text guidance**
   - Use ΔAIC within scenario to shortlist runs.
   - Use hindcast MASE and retrospective diagnostics to assess short-term predictive skill and stability.
   - Use Kobe and management simulations to illustrate the consequences of run selection on advice.

Captions and cross-references (placeholders)

- **Figure (?)(fig:compare_SC0)** — SPiCT comparison plot for Scenario SC0 (RUN1–RUN4).
- **Figure (?)(fig:hindcast_SC1_RUN1)** — Hindcast diagnostics for SC1 RUN1; panel titles contain MASE values.
- **Figure (?)(fig:Kobe_SC1)** — Kobe plot for Scenario SC1 (four prior configurations).
- **Table (?)(tab:aic)** — AIC by scenario and run (used to compute ΔAIC within scenario).
- **Table (?)(tab:mase)** — Hindcast MASE by scenario, run and index.

- **Table (?)(tab:mohn)** — Mohn's rho (retrospective) by scenario and run.
- **Table (?)(tab:management)** — Management summary for ICES (2025) HCR per fit.

The combined diagnostics show that no single metric is sufficient to identify the "best" run. I recommend selecting a preferred run within each scenario by applying a simple decision rule that weights (1) ΔAIC (within scenario), (2) hindcast MASE averaged across indices, and (3) Mohn's rho for B/BMSY; when two or more runs are numerically similar, favour the run with superior visual fit to the long, fishery-independent survey used as a primary index. The figures and tables listed above provide the necessary evidence to document the selection process in the Working Document.

Conclusions

WGBIE considered the results obtained for Nephrops FU 30 stock promising and will propose it as possible candidate for the next WKMSYSPiCT benchmark. However, further work should be conducted to improve the model according to the most recent SPiCT guidelines (Mildenberger et al., 2023). The WKMSYSPiCT benchmark, where a close contact with SPiCT expert is possible, could help to find the best model configuration to provide the assessment for this stock. Further work is needed to improve the model, including:

- Extend the time series of landings to earlier years in order to improve the stability and robustness of the model
- Add uncertainty in some years of the biomass indices time series or catches
- Fine-tune model configuration.

Code Repositories

All this work has been developed using R language. The code and data used for the SPiCT explorations for Nephrops FU30 can be found in the following GitHub repository:

Figures and Tables

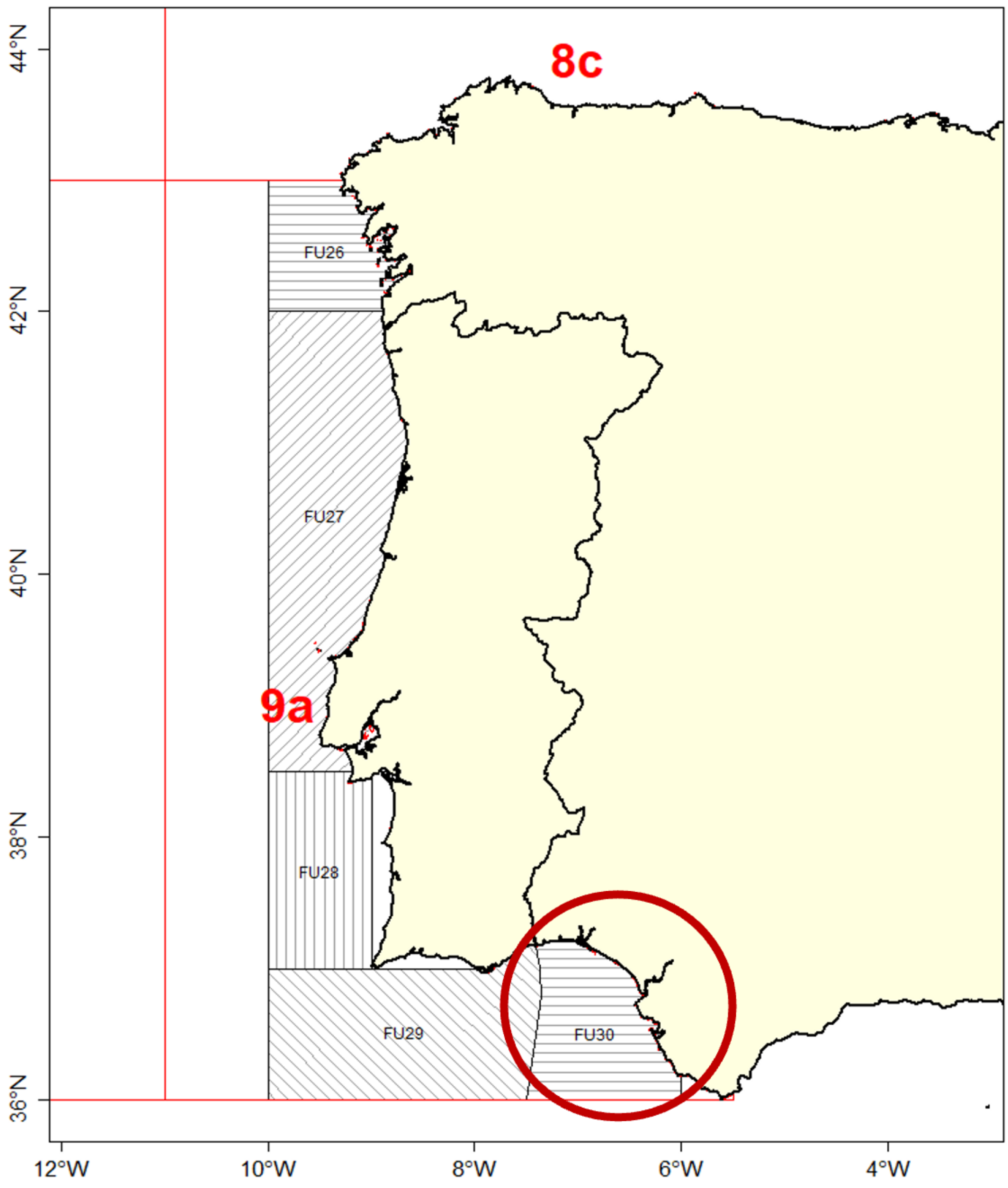

Figure 1: Map of the Gulf of Cádiz (FU30, Division 9.a) showing the main fishing grounds for Nephrops norvegicus.

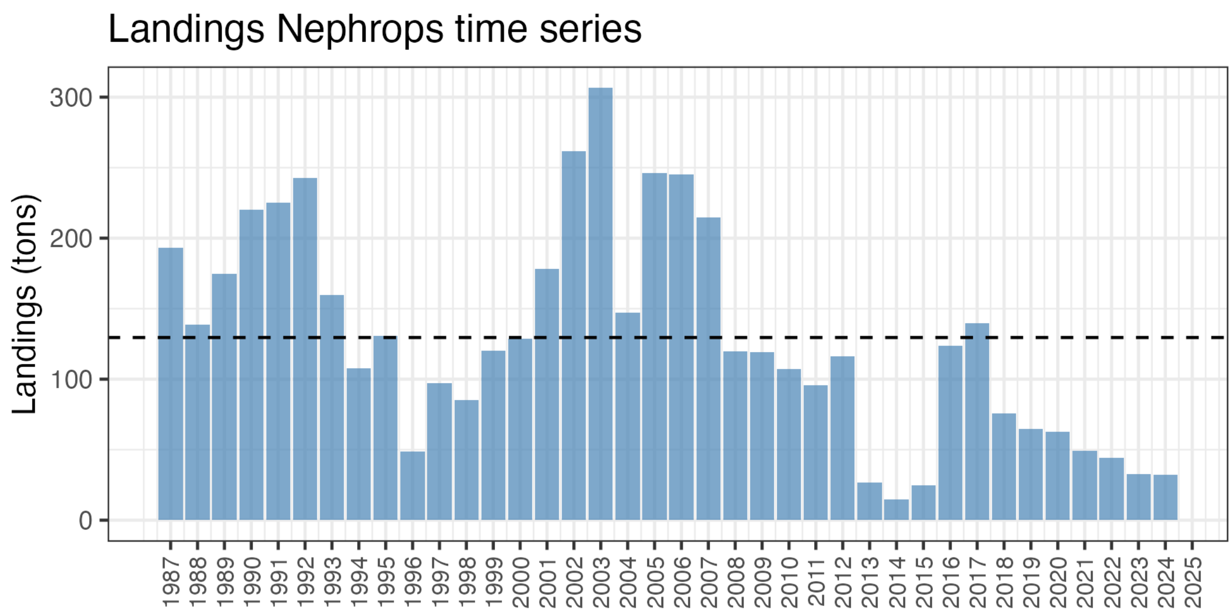

Figure 2: Time series of annual Nephrops landings (tons) for FU30 (Division 9.a). Bars represent reported annual catches, while the dashed horizontal line indicates the long-term mean catch over the period analysed.

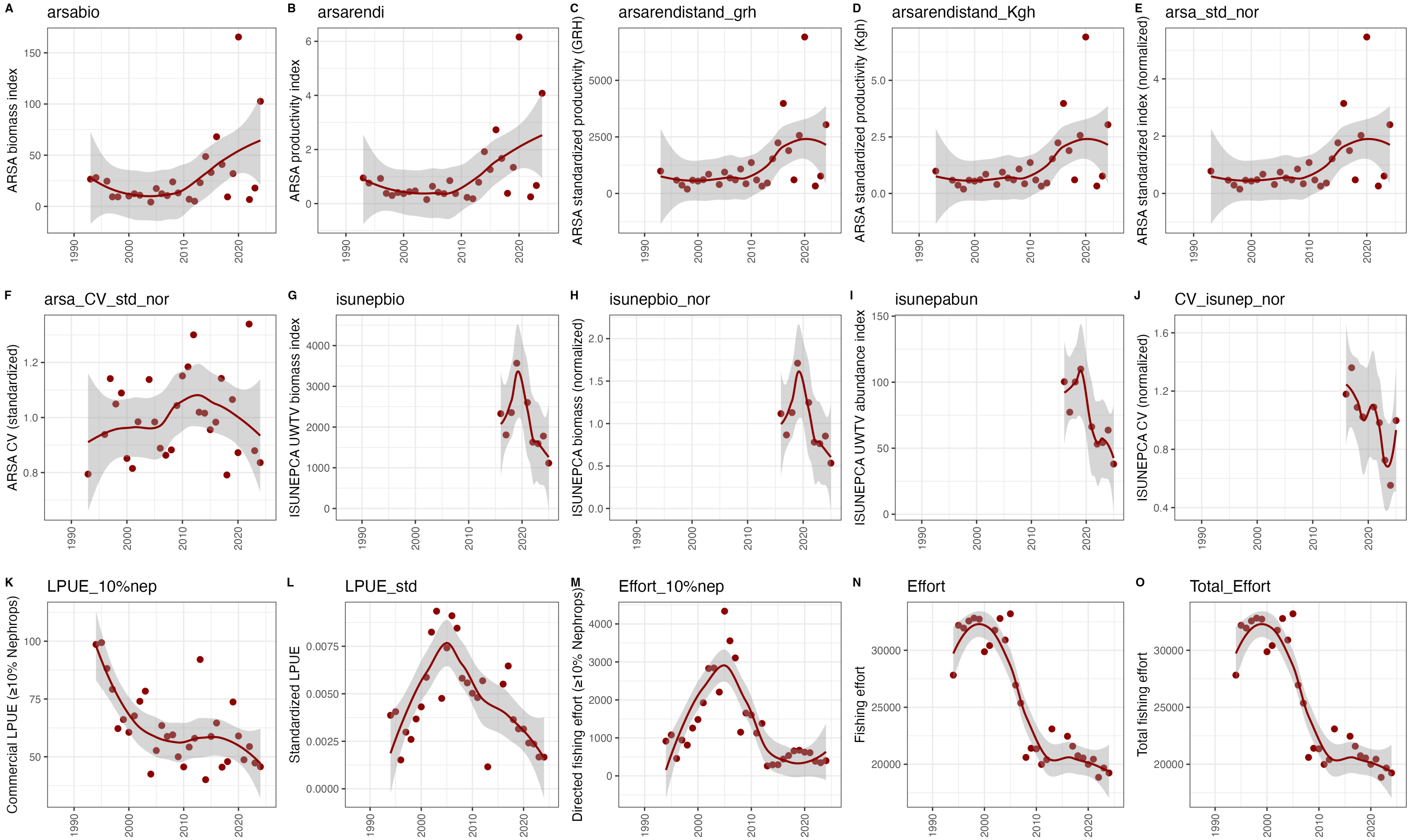

Figure 3: Time series of abundance and fishery-dependent indices used in the SPiCT explorations for Nephrops FU30 (Division 9.a). Panels A–H show the different survey-based and commercial indices. Points represent observed annual values, while solid lines correspond to smoothed trends with associated uncertainty envelopes.

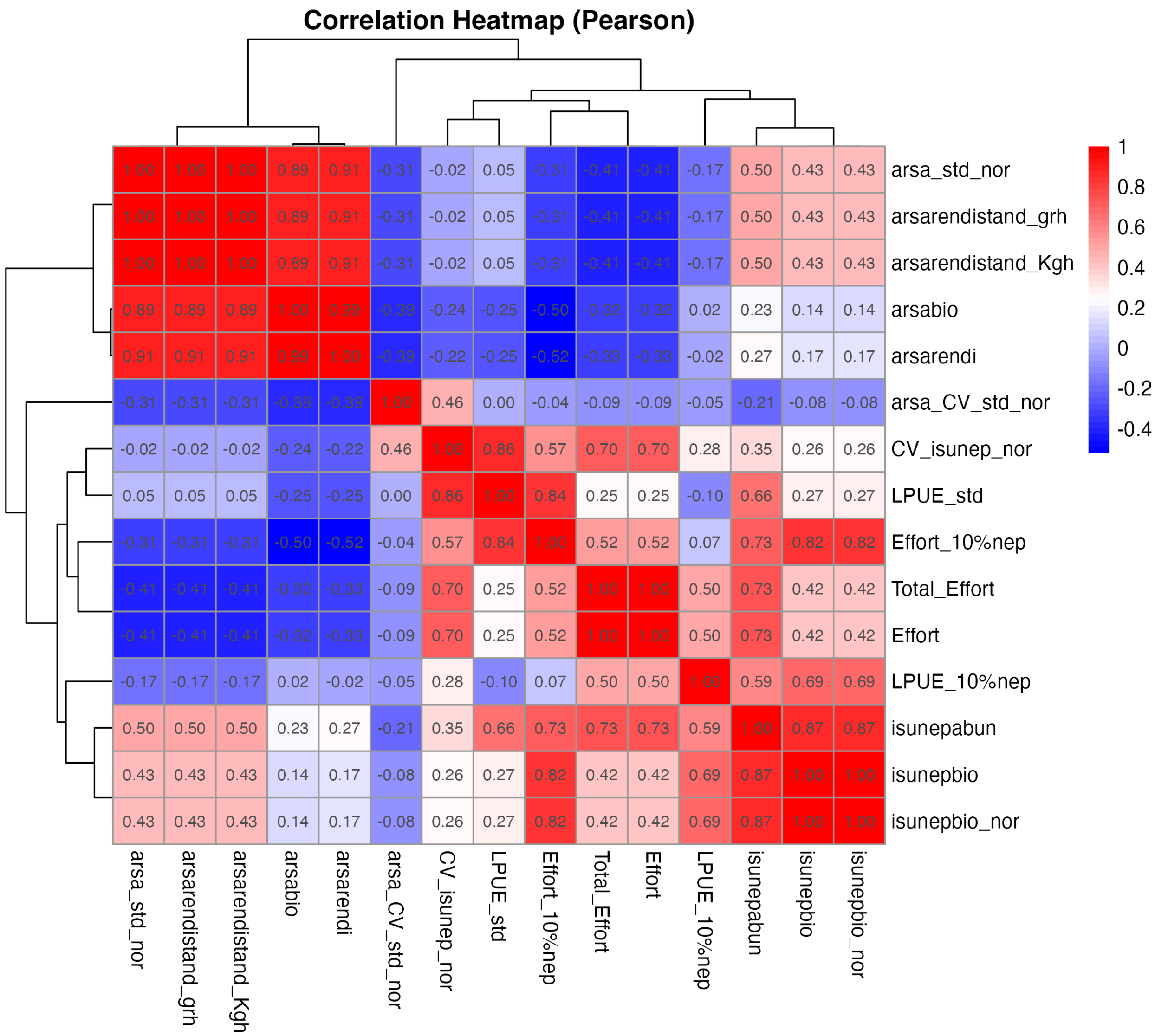

Figure 4: Spearman rank correlation heatmap among abundance, productivity and fishery-dependent indices for Nephrops FU30 (Division 9.a). Colours indicate the strength and direction of correlations (red: positive; blue: negative), and hierarchical clustering highlights groups of highly correlated indices.

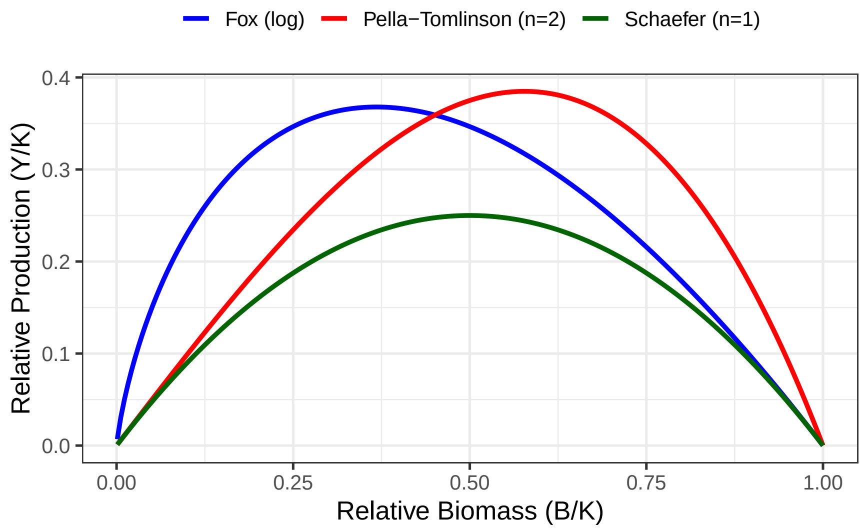

Figure 5: Comparison of surplus production functions: Schaefer (n=1), Pella–Tomlinson (n=2) and Fox (log).

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