Review of Sea Bass Harvest Strategies and Alternatives

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Executive Summary

Aims: This review supports delivery of the Bass Fisheries Management Plan (FMP), developed under the UK Fisheries Act 2020. The work was funded by the Marine Management Organisation (MMO) and 144 Crowdfunder donors seeking an excellent bass fishery for all as a mixed commercial–recreational fishery. The review (i) assesses the current ICES MSY-based framework for bass; (ii) draws on international examples of mixed commercial–recreational fisheries and harvest strategies; and (iii) sets out a practical, stakeholder-informed co-development pathway for developing an alternative bass-specific harvest strategy. The pathway can be developed using Management Strategy Evaluation (MSE) and explicitly includes biological, economic, social, and ecosystem objectives.

Why the current approach needs updating: Bass is currently managed under the ICES MSY framework, which is designed to optimise long-term yield using reference points based on total biomass and fishing mortality. Bass FMP Goals 5 and 6, however, require considering broader outcomes. These include maximising social and economic benefits for coastal communities, ensuring ecosystem health and resilience, protecting stock and size structure, and delivering fair outcomes across sectors. For bass, important to both commercial and recreational sectors, a yield-based framework alone will not necessarily deliver these wider goals. Especially as recent work has indicated that current methods for setting ICES MSY reference points may not always be sufficiently precautionary as they do not take into account the full impact of uncertainty. This reinforces the need for a bass-specific, goal-based strategy. Since bass as a shared UK–EU stock, delivering the FMP objectives requires working within ICES to develop and benchmark the advice framework.

How to broaden the approach: Adopt a more precautionary, multi-goal harvest strategy for bass that treats F_{MSY} as an upper limit rather than a target. Use a lower F for setting catch advice. e.g. below F_{MSY}, and explicitly safeguard large fish and stock structure. Define biomass targets (e.g. B_{target}) and adopt a Large Fish Strategy (LFS) to maintain robust age/size structure. Incorporate rebuilding-time reference points (B_{rebuild}, T_{rebuild}) that are activated if stock indicators fall below agreed thresholds. Evaluate candidate strategies through MSE against biological, economic, social–cultural, and ecological

objectives. This requires alternative scenarios based on an ensemble of operating models to represent uncertainty in population dynamics, data quality, and implementation. Two linked proposals are therefore made: (i) adopt an interim, more precautionary F target within the existing joint UK–EU Multiannual Plan (MAP); and (ii) develop a longer-term bass-specific harvest strategy after MSE has evaluated trade-offs across objectives.

International practice: Mixed commercial–recreational fisheries internationally use explicit sector allocations, precautionary F targets and stock health indicators; these tools are feasible for bass and improve biological and socio-economic outcomes when embedded in clear governance processes. These approaches can be adapted to the UK bass context.

Roll–out, three-part policy structure.

1. *Co-designed Alternative Framework:* Agree management objectives and decision metrics up-front; use MSE to evaluate candidate harvest strategies that use F_{MSY} as an upper limit, incorporate rebuilding-time-based reference points, and make trade-offs between multiple Bass FMP goals explicit for managers and stakeholders.
2. *Sectoral Allocations:* Make allocation explicit; ensure dead discards and post release mortality count against respective allocations; protect low-impact inshore/small-scale participation; retain gear-specific controls.
3. *Time-bound Actions:*
   - **Short term (0–12 m):** initiate MSE; strengthen monitoring (including digital recreational reporting); set accounting rules and interim F target within the MAP.
   - **Medium term (1–3 y):** develop performance metrics based on the agreed objectives, complete OM/MSE, develop operational reference points, and assess trade-offs.
   - **Longer term (3–5+ y):** implement the selected harvest strategy; embed maximum economic yield and maximum social benefits concepts as data improve; establish routine and exceptional-circumstances reviews.

Interim recommendation: To reduce risk adopt the lower end of the MAP F range ($\approx$0.145) now as a MAP-consistent interim operational target while MSE is developed; then test alternatives such as $0.6 \times F_{\text{MSY}}$ in the bass-specific MSE to quantify risk–yield and rebuilding trade-offs before any further change.

Contents

1 Technical Summary

The aim of this ***"Review of Sea Bass Harvest Strategies and Alternatives"*** is to support the UK Bass Fisheries Management Plan (FMP) and UK Fisheries Act 2020 objectives. This Technical Summary is intended to show how the existing framework can be adapted, recognising that fisheries management authorities must work within the MAP and the ICES process, and to set out constructive proposals that are operationally feasible within those constraints. To do this the report (i) conducts a comprehensive assessment of the current ICES MSY-based management framework, (ii) reviews alternatives from global examples of mixed commercial–recreational fisheries, and (iii) proposes a multi-objective framework for evaluating and developing alternative management strategies.

Current management framework and case-specific adaptation: The current ICES MSY-based framework has been applied across many European fisheries, primarily against yield and precaution criteria. For bass, however, this is not sufficient on its own. Sea bass is a mixed commercial–recreational fishery with broader and potentially conflicting objectives. These include maximising social and economic benefits for coastal communities, ensuring ecosystem health and resilience, protecting demographic population structure, and achieving equitable distribution of benefits across sectors. This requires case-specific harvest rules tested through Management Strategy Evaluation (MSE). Recent research also indicates that when realistic uncertainty is represented (assessment error, implementation error, and biological process variability), outcomes may be less precautionary than expected.

For example, in the bass benchmark where outputs from SS3 were used as inputs to EQSIM, a diagnostic concern is that the precautionary biomass trigger (linked to the hockey-stick breakpoint) can end up close, or even above the MSY biomass level, making the limit-versus-target interpretation awkward once closed-loop feedback is considered. This reinforces the case for bass-specific testing in closed-loop MSE.

Proposal: The proposed framework treats F_{MSY} as an upper bound rather than a target. It uses lower operational fishing mortalities and explicit rebuilding-time reference points ($B_{\text{rebuild}}, T_{\text{rebuild}}$). These are activated when biomass or structural indicators fall below agreed thresholds. The framework also implements a Large Fish Strategy (LFS) to maintain robust age and size structure. Candidate strategies are tested through MSE against biological, economic, social–cultural, and ecological objectives. Enhanced monitoring supports both MSE development and sector allocation, recognises recreational fishing as a core stakeholder objective, and enables rapid implementation of pre-agreed rebuilding actions when shocks occur.

Timeframe: Short term (0–12 months): Initiate MSE framework development and enhance recreational and commercial monitoring. **Medium term (1–3 years):** Complete Operating Model development, run MSE evaluation, agree management objectives and performance metrics, develop rebuilding-time reference points (B_{rebuild}, T_{rebuild}, B_{target}), and pilot management measures. **Long term (3–5+ years):** Implement the selected management strategy, embed Maximum Economic Yield (MEY) and Maximum

Societal Benefits (MSB) frameworks as economic data improve, and establish routine review cycles for adaptive management. MSE development should start immediately and is a prerequisite for delivering Bass FMP goals; it should not be postponed for 5–10 years. A 5-year development period is realistic, and some benefits can be realised earlier with shortcut and empirical management procedures.

1.1 Key Messages for Policy

Policy Implications

- **Bass needs case-specific harvest rules**: The current ICES MSY-based framework works well for many stocks, but bass has mixed-sector dynamics and higher uncertainty in removals. EQSIM-based F_{MSY} estimates therefore need additional precautionary testing in closed-loop MSE with realistic assessment, implementation, and process uncertainty.
- **Stock currently above $MSY\ B_{\mathrm{trigger}}$ and can support more ambitious goals**: The stock is currently in a good position and can support management objectives beyond simple MSY maximisation, including Large Fish Strategy outcomes, improved age/size structure, and enhanced social and economic benefits.
- **Immediate switch to lower F within MAP**: Adopt the lower end of the MAP range ($F \approx 0.145$) as an interim operational target. This is less conservative than the $0.6 \times F_{\mathrm{MSY}}$ benchmark proposed by [1] ($0.6 \times 0.170 \approx 0.102$), but still provides immediate risk reduction with minimal governance change while MSE is developed.
- **Urgent development of bass-specific MSE**: MSE development should start immediately and is a prerequisite for delivering Bass FMP goals; it should not be postponed for 5–10 years. A 5-year development period is realistic, and some benefits can be realised earlier with shortcut and empirical management procedures.
- **Improved recreational and commercial monitoring**: Enhanced monitoring is needed to support MSE development, sector allocation, and risk analysis, not to reopen basic questions about the existence of recreational and commercial removals.

1.2 Key Findings

1: Current Management Framework: The current ICES MSY-based framework has been applied across many European fisheries. Its performance is strongest where objectives are primarily yield and biomass-risk based. For bass, as a mixed commercial–recreational fishery with multiple objectives, case-specific considerations include:

- For bass, with high uncertainty in recreational removals and mixed-sector dynamics, F_{MSY} estimates may benefit from additional precautionary testing in closed-loop MSE frameworks that incorporate realistic sources of uncertainty.
- For stocks with high uncertainty like bass, current modelling approaches may benefit from additional testing to ensure robustness across different assessment assumptions. For example, successive bass benchmarks and updating of assessment can result in

large changes in perceived stock status, and hence catch advice, highlighting the value of MSE testing to ensure harvest strategies remain robust.

- The current ICES MSY-based framework focuses on maximum sustainable yield, which is appropriate for many stocks. MSY should not be interpreted as full social–ecological sustainability on its own. For bass, FMP objectives extend beyond MSY to include economic, social, and ecosystem outcomes. The framework can be adapted case by case to address these additional objectives.

2: Global Examples: International case studies illustrate that:

- Mixed commercial–recreational fisheries can benefit from explicit sector-specific allocation and management tools, where biological, economic, social, ecological objectives are integrated through structured frameworks.
- Alternative reference points based on economics and size structure (i.e. large-fish protection) and more precautionary F targets are feasible
- Formal sector allocation, enhanced monitoring, and stakeholder engagement can help in achieving successful management.

3: Alternative Strategies: An alternative management framework could include:

- Evaluation of using F_{MSY} as an upper bound rather than a target, using lower operational fishing mortalities (e.g., $F = 0.6 \times F_{\text{MSY}}$).
- Development of explicit targets (biomass as current, but also others such as abundance of large fish) and associated time frames for achieving them.
- Evaluation of performance against biological, economic, social–cultural, and ecological metrics
- Integrates sector-specific considerations recognising diverse commercial and recreational stakeholders
- Provides a phased implementation roadmap with clear timelines and decision points

Recommendations

The following summarises potential actions to achieve the Bass FMP and then proposals to meet them.

Immediate Actions (0–12 months): Actions:

- Consult stakeholder advisory group(s).
- Enhance recreational monitoring through digital catch reporting.

Proposals to meet these actions:

- Initiate MSE framework development.

- Evaluate alternative management advice for a range of management objectives identified by stakeholders, e.g. consequences of using F_{MSY} as an upper limit on catches and proportion of large fish.

Medium-Term (12–36 months): Actions:

- Expand economic and social data collection.

Proposals to meet these actions:

- Agree management objectives and develop performance metrics that allow them to be evaluated.
- Complete Operating Model development and specification of candidate harvest strategies.
- Run MSE evaluation of alternative strategies.
- Build stakeholder consensus on preferred strategy.

Long-Term (36–60 months): Actions:

- Establish monitoring and review protocols.
- Refine strategy based on consultation and review.

Proposals to meet these actions:

- Implement selected management strategy with UK–EU coordination.
- Conduct a full implementation review after the new advice framework has been running for a number of years

Expected Benefits

The alternative management strategy is expected to deliver benefits across a range of objectives:

- **Biological:** Lower risk of stock depletion (probability of $B < B_{\text{lim}} < 5\%$), and improved resilience through stock structure. Explicit rebuilding objectives if stock declines due to environmental shocks.
- **Economic:** Higher value from both commercial and recreational sectors, better catch per unit effort, improved profitability, stronger coastal community economies.
- **Social:** More equitable distribution of benefits, stronger recreational fishing experiences, enhanced coastal community well-being.
- **Ecological:** Larger stock biomass, better age and size structure, reduced bycatch and habitat impacts
- **Governance:** Transparent, evidence-based, stakeholder-aligned decision-making.

Conclusion

This Review of Sea Bass Harvest Strategies and Alternatives provides a comprehensive evidence base for transitioning bass management towards a more precautionary, multi-objective, and stakeholder-aligned framework.

The current ICES MSY-based framework has been applied across many European fisheries. For bass, the key question is whether it meets the full Bass FMP objective set. The ICES process allows review and adaptation from generic to case-specific approaches. For a mixed commercial–recreational fishery such as bass, case-specific harvest rules are therefore appropriate. International evidence indicates that viable alternatives exist and can be tested robustly through MSE.

The proposed alternative management strategy developed here addresses Bass FMP Goals 5 and 6 [2]: through higher and more stable biomass (supporting coastal communities and recreational catch rates), more stable yields and reduced risk of breaching limit reference points (supporting commercial and recreational sectors), and a multi-objective evaluation and stakeholder process that aligns with the FMP's emphasis on social and economic benefits and ecosystem health.

It treats F_{MSY} as an upper bound rather than a target, uses explicit rebuilding objectives, evaluates performance against multiple criteria, and integrates sector-specific considerations.

A phased implementation roadmap allows for testing, refinement, and stakeholder buy-in.

Success will depend on continued scientific development, strong stakeholder engagement, investment in data systems and monitoring, adaptive governance, and long-term commitment to iterative improvement based on performance evaluation and learning.

How to read this report

Policy readers: focus on the Executive Summary and Sections 2–4, especially the communication and implementation material in Sections 4.4–4.6. Technical readers: see the Appendices (A–M) for detailed methods, data, operating/observation model specifications, conditioning procedures, and validation.

2 UK Sea Bass Fishery

This chapter answers: What does the current ICES MSY-based framework do for bass, where are its strengths/limitations for a mixed commercial–recreational fishery, and how does it align with Bass FMP and Fisheries Act 2020 objectives? It summarises the advice rule, current status and key uncertainties, and identifies where case-specific adaptation (tested through MSE) can better support statutory ecological, social and economic goals.

The **Bass Fisheries Management Plan (FMP)**, developed by Defra and the Welsh Government under the Fisheries Act 2020, establishes a statutory framework to ensure long-term sustainable management of bass fisheries in English and Welsh waters [2]. The *Bass FMP* (along with its associated goals, timelines, and instruments) is the UK-specific statutory framework for English and Welsh waters, and is the primary policy context for this report. The plan was co-designed through a 2023 stakeholder consultation process and seeks to balance ecological, social, and economic objectives across sectors. ICES advice sometimes refers to a "precautionary management plan" for the EU.

For policy readers, the key Bass FMP goals relevant to this review are:

- **Goal 5**: maximise social and economic benefits for coastal communities and fishers, including equitable distribution of benefits across commercial and recreational sectors.
- **Goal 6**: ensure ecosystem health and resilience, including protection of demographic population structure (age/size), spatial distribution, and wider ecosystem considerations (EBFM).

This **Review of Sea Bass Harvest Strategies and Alternatives** evaluates how the ICES MSY Approach can be adapted for bass to better align with Bass FMP objectives and relevant international commitments. The review (i) assesses the current ICES maximum sustainable yield (MSY)–based management framework, including stock assessment methodology and reference point estimation in light of recent research [3], (ii) examines international examples of harvest strategies in mixed commercial–recreational coastal fisheries to identify potential approaches applicable to bass management in a bilateral UK–EU context, and (iii) proposes case-specific alternatives that can be developed using Management Strategy Evaluation (MSE) within the ICES framework. These alternatives are consistent with Bass FMP objectives and stakeholder priorities, build on international case studies, and are tailored to the specific characteristics of bass as a mixed commercial–recreational fishery. For a concise overview of objectives and policy actions, see the Executive Summary and Section 4. For technical details of the ICES framework and reference-point estimation, see Appendices.

Despite the many successes of the ICES MSY Approach across European fisheries, sea bass has specific characteristics as a mixed commercial–recreational fishery that could benefit from case-specific harvest rules to fully address the varied and potentially conflicting objectives set out in the Bass FMP and Fisheries Act 2020. These objectives include maximising social and economic benefits for coastal communities, ensuring ecosystem health and resilience, protecting demographic population structure, and achieving equitable distribution of benefits across commercial and recreational sectors. The ICES framework optimises long-term yield, which is appropriate for many stocks, but for bass the FMP objectives extend beyond MSY maximisation. In other words, MSY performance alone is not sufficient to demonstrate delivery of the full policy objective set. The ICES framework explicitly allows for review and adaptation, moving from generic approaches to frameworks that are better tailored to the specific characteristics of a resource. For bass, this means developing harvest control rules that explicitly address multiple objectives through Management Strategy Evaluation, recognising that commercial and recreational sectors have different values, objectives, and management needs.

2.1 ICES MSY Approach

2.1.1 The ICES MSY Advice Framework

As a stock shared with the European Union, annual catch advice is provided by ICES using a generic MSY advice rule [4]. This advice sets catch limits based on fishing mortality (F) linked to spawning stock biomass (SSB) via biological reference points.

The ICES framework comprises three key elements:

Target Reference Point: The fishing mortality at MSY, F_{MSY}, defined as the exploitation rate (fishing mortality) that *generates* maximum long-term average yield (MSY). This is derived from stochastic simulations, subject to the precautionary constraint that fishing at F_{MSY} maintains a low probability (5%) of SSB falling below the limit biomass B_{lim} [4, 5].

Biomass Reference Points: provide limits and thresholds to ensure that productivity and sustainability is not impaired:

- B_{lim}: limit biomass below which recruitment is considered impaired and the stock has reduced reproductive capacity [4].
- $MSY\ B_{\text{trigger}}$: biomass level (often set equal to B_{PA}) at or above which fishing at F_{MSY} is permitted [4].

Harvest Control Rule: ICES uses a generic advice rule that operates as follows [4]:

- If $SSB \geq MSY\ B_{\text{trigger}}$, advise catches corresponding to $F = F_{\text{MSY}}$.
- If $B_{\text{lim}} < SSB < MSY\ B_{\text{trigger}}$, reduce F linearly with SSB:

$$F = F_{\text{MSY}} \times \frac{SSB}{MSY\ B_{\text{trigger}}}.$$

- If $SSB \leq B_{\text{lim}}$, advise lowest possible catches to allow rapid rebuilding above B_{lim}.

In practice, age-structured stock assessments estimate current SSB and F, and stochastic projections (that include uncertainty about future recruitment) derive F_{MSY} and associated biomass reference points [6], which are then applied through the ICES advice rule to generate annual catch recommendations.

2.1.2 Current Stock Status

The most recent ICES advice for sea bass in divisions 4.b–c, 7.a and 7.d–h, following the 2025 benchmark assessment [WKBSEABASS; 7], estimated spawning stock biomass to be above $MSY\ B_{\text{trigger}}$ and B_{lim}, with fishing mortality on ages 4–15 below F_{MSY}, placing the stock within safe biological limits.

Total removals in 2026 (commercial landings, commercial dead discards, recreational retained catch, and recreational release mortality) were recommended not to exceed 5,180 t [8].

This represents a substantial change from the ICES 2023 advice for 2024 catches (2,432 t [9]; see Table 1), reflecting revisions to the assessment model, stock status estimates, and reference points that led to higher perceived stock productivity and biomass. The large increase in advised removals (more than doubling from 2,432 t to 5,180 t, a 113% increase) arises primarily from methodological changes in the assessment and reference point estimation, rather than clear changes in underlying biology. This dramatic shift illustrates an important sensitivity of the current management approach: its dependence on model structure and technical assumptions can create instability in management advice, where successive assessment updates produce large changes in perceived stock status and catch recommendations. This has been a focal point for stakeholder concern and underscores the need for robust, transparent ways of handling uncertainty and rebuilding objectives for bass.

The jump in catch advice illustrates why Management Strategy Evaluation (MSE) is valuable: MSE tests harvest strategies across an ensemble of Operating Models representing key uncertainties, helping ensure that management advice remains robust and stable even when assessment methods or reference point estimates change. By evaluating candidate harvest control rules under realistic uncertainty, MSE can identify strategies that perform well across multiple plausible scenarios, reducing the risk of large swings in advice due to assessment revisions (e.g. following benchmark updates). For bass, key drivers of the benchmark-related change included:

1. Explicitly accounting for connectivity with the Bay of Biscay stock (reallocating 14.6% of catches to stock bss.27.8ab) [7, 8];
2. Incorporating additional recruitment information from dedicated surveys (Solent, Fal and Hel, Nourdem) [7];
3. Adopting Stock Synthesis 3 [SS3; 10] with revised natural mortality and stock-recruitment assumptions [7].

2.1.3 Scientific Advice Framework

The robustness of the advice, depends on the assessment methodology, data sources, and key uncertainties underpinning stock status estimates [7].

The stock is assessed using Stock Synthesis 3 (SS3), which provides a maximum likelihood framework combining multiple data sources with different error structures [10]. The model is age-structured with ages 0 to 15+, where 15+ represents a plus group containing all fish aged 15 years and older [7].

Table 1: Comparison of ICES reference points and recent stock status before and after the 2025 benchmark.

	2023 (Pre-benchmark)	2025 (Post-benchmark)
Advice (total removals)	2,432 t	5,180 t
Recent SSB (t)	12,899 (SSB_{2023})	25,330 (SSB_{2026})
SSB status	$B_{\text{lim}} < \text{SSB} < MSY\ B_{\text{trigger}}$	$\text{SSB} > MSY\ B_{\text{trigger}}$
B_{lim} (t)	10,313	15,666
$MSY\ B_{\text{trigger}}$ (t)	14,439	19,339
F status	$F < F_{\text{MSY}}$	$F < F_{\text{MSY}}$
Recent F (ages 4–15)	0.113 (2022)	0.104 (2025)
F_{MSY}	0.1713	0.170

Note: ICES assessment and advice in this report are taken from: (i) ICES Working Group on Benchmark for Sea Bass (WKBSEABASS) 2025 [7] for post-benchmark reference points, stock status, and assessment methodology; and (ii) ICES Advice 2023 for stock bss.27.4bc7ad–h [9] for pre-benchmark reference points and advice for 2024 catches.

Data Sources: The SS3 assessment integrates multiple data types, each with distinct strengths and limitations.

Commercial Landings and Discards: The assessment incorporates international commercial landings from France, the United Kingdom, and Belgium, disaggregated by fleet and gear type (bottom otter trawl, nets, hooks and lines, and other passive gears). Commercial discard estimates are available from 2009 onwards, derived from observer sampling programmes with variable coverage creating substantial uncertainty [7, 8].

Commercial LPUE Index: A standardised Landings Per Unit Effort (LPUE) index serves as a proxy for stock abundance trends [7]. The LPUE series was corrected following the 2018 benchmark after an error affecting historical fishing mortality and SSB estimates was discovered [11]. The index remains subject to multiple biases including changes in fishing behaviour, spatial effort distribution, technological improvements (effort creep), and market demand shifts.

Recreational Removals: Recreational removals constitute approximately 45–50% of total bass mortality [8, 7]. The assessment includes estimates from both UK and France covering shore-based and boat-based rod-and-line fishing. Data are derived from periodic surveys and monitoring programmes rather than mandatory reporting. A key assumption is 5% post-release mortality for recreationally caught and released bass [7], though the absolute scale of recreational removals remains highly uncertain.

Survey Indices: The Solent Bass Pre-Recruit Survey, conducted by Cefas since 1983, provides a critical recruitment index monitoring abundance of juvenile bass (ages 0–4) in one of the most important English Channel nursery areas [7]. Additional recruitment surveys (Fal and Helford sea prerecruit survey, French Nourdem survey) were incorporated in the 2025 benchmark [7]. While recent years (2020–2021) showed higher-than-average recruitment, overall recruitment remains variable and generally poor since 2008 [8], suggesting the importance of conserving strong year-classes until they can join the adult population and reproduce.

Biological Assumptions:

Growth and Maturity: The assessment uses von Bertalanffy growth parameters to model length-at-age relationships [12].

Maturity-at-age is incorporated through a logistic maturity ogive, with 75% of female and male bass mature at 44 cm and 37 cm, respectively [7]. These parameters determine spawning stock biomass (SSB) as the product of numbers at age, maturity, and weight.

Natural Mortality: Natural mortality (M) is a key parameter. The bass assessment revised natural mortality estimates in the 2025 benchmark, though specific values are not explicitly stated in recent advice documents. Empirical relationships between growth parameters, temperature, and maximum age are often used to estimate M when direct estimates are unavailable [13, 14].

Selectivity: Stock Synthesis allows flexible modelling of fishery and survey selectivity patterns [10]. For bass, selectivity was modelled using double-normal functions allowing representation of both asymptotic selectivity (vulnerability plateaus for larger fish) and dome-shaped selectivity (vulnerability peaks then declines for largest fish) [7]. Selectivity parameters are estimated within the model using age/length composition data, varying by fleet and potentially over time.

Stock-Recruitment Relationship: The assessment incorporates a stock-recruitment relationship to model recruit production as a function of spawning stock biomass. The most commonly used forms in ICES assessments are the Beverton-Holt model [15] or the segmented regression (hockey stick) model [16].

For ICES assessments, the segmented regression function is commonly used for reference point calculations, with the breakpoint set at B_{lim} [4], considered consistent with precautionary considerations. For stocks with high uncertainty like bass, where natural mortality estimates are poorly constrained, segmented regression estimates of B_{lim} may be more uncertain. The method is sensitive to data range and influential observations; routine assessment updates may cause shifts in breakpoints. For bass, alternative approaches using continuous smooth hockey stick models or forward-looking rebuilding-time-based reference points may complement the ICES framework, which allows for such case-specific adaptation (see Rebuilding Time-Based Reference Points).

Reference Point Estimation: These biological parameters and stock-recruitment assumptions are combined to estimate biological reference points that guide management advice. The EQSIM software implements stochastic equilibrium simulations to derive reference points [6]. Pre-benchmark reference points ($B_{\text{lim}} = 10{,}313$ t, $MSY\ B_{\text{trigger}} = 14{,}439$ t,

$F_{\text{MSY}} = 0.1713$) are from ICES Advice 2023 for bss.27.4bc7ad–h [9] (ICES 2019 assessment). Post-benchmark reference points are: $B_{\text{lim}} = 15{,}666$ t, $B_{\text{PA}} = MSY\ B_{\text{trigger}} = 19{,}339$ t, and $F_{\text{MSY}} = 0.170$ [7, 8].

Key Assessment Uncertainties and Risk: Despite advances in data collection and modelling, several sources of uncertainty substantially affect stock status estimates and advice [8]. For stocks with high uncertainty like bass, these uncertainties can create challenges when assessments are updated annually or through benchmark processes. The ICES framework allows for case-specific adaptation, and MSE testing across an ensemble of Operating Models can help ensure harvest strategies remain robust across different assessment assumptions.

Sources of Uncertainty:

Recreational Removals While multi-national survey data since 2010 allow annual estimates of recreational removals, the absolute scale remains poorly constrained. The benchmark explored alternative historical series before selecting assumptions based on diagnostics, potentially not fully reflecting uncertainty. Sensitivity to these choices could affect estimates of status relative to reference points and thus catch advice.

Stock Structure and Connectivity Stock structure between bss.27.4bc7ad–h and the neighbouring Bay of Biscay stock bss.27.8ab remains uncertain. Connectivity between areas continues as a major source of uncertainty; management measures in one area will affect the other stock and vice versa.

Discards and Bycatch Discards are only included for some fleets and are derived from incomplete sampling and logbook information (especially for 2000–2008). Discarding has increased since prohibition of directed sea bass fishery in 2015, and actual discard mortality may differ from model assumptions.

Recruitment Recruitment in 2025–2026 is based on a stock-recruit relationship informed by several surveys, but future recruitment remains uncertain. Projections of SSB and probability of falling below B_{lim} are sensitive to these assumptions.

Natural Mortality and Steepness Uncertainty in natural mortality M and stock-recruit steepness h, typically fixed parameters, have strong impacts on estimates of stock status and reference points. The benchmark constructed an uncertainty grid over M and h using likelihood profiles to identify where data support or contradict chosen base values, locate conflicts between datasets, and explore how alternative parameter combinations would shift inferred dynamics and management advice.

Problems with Assessment Updates: Fisheries management decisions must account for uncertainty in stock assessments, yet traditional approaches often rely on a single "best" model that may not adequately represent the full range of plausible scenarios. This creates several problems when assessments are updated:

Reliance on a single model specification: means that management advice may shift dramatically when new data become available or when model assumptions are revised. For sea bass, the 2025 benchmark assessment provides a stark illustration: advised removals more than doubled from 2,432 t (2023 advice for 2024) to 5,180 t (2025 advice for 2026), despite actual fishing mortality remaining relatively stable ($F = 0.113$ in 2022 vs $F = 0.104$ in 2025) and no evidence of corresponding biological changes. This 113% increase in advised removals arose primarily from technical changes in the assessment methodology (adoption of SS3, revised natural mortality and stock-recruitment assumptions, incorporation of additional survey data, reallocation of catches between stocks) rather than changes in underlying stock dynamics. Such inconsistency undermines confidence in management and creates challenges for long-term planning for both managers and stakeholders. This demonstrates why Management Strategy Evaluation (MSE) is valuable: i.e. by testing harvest control rules across an ensemble of Operating Models that represent key uncertainties (including alternative assessment assumptions), MSE can identify strategies that remain robust and stable even when assessment methods or reference point estimates change, preventing large swings in advice due to technical revisions.

A best assessment approach: may fail to adequately quantify risk. The probability of undesirable outcomes (e.g., stock falling below limit reference points) depends not only on the central estimate but on the full distribution of plausible scenarios. When uncertainty is not explicitly represented, management advice may appear more precise than is justified, potentially leading to over-optimistic catch recommendations that increase the risk of stock depletion.

Assessment updates: can reveal that previous advice was based on incorrect assumptions, but by then management measures may already have been implemented. The retrospective patterns, where terminal-year estimates shift as new data are added, demonstrate that even well-fitted models may not accurately predict future stock status. This creates a feedback loop where assessment uncertainty contributes to implementation uncertainty, which in turn affects future assessments. This has led to calls for ensemble modelling and MSE-based evaluation of harvest strategies that are less sensitive to individual assessment updates.

2.1.4 Sea Bass Specific Considerations

The ICES MSY Approach has been applied across many European fisheries, providing a robust and precautionary framework for yield-focused management objectives. At the same time, outcomes across EUUK stocks have been mixed, with many stocks not rebuilt above B_{MSY} by 2020, reinforcing the need to judge performance against explicit biomass and rebuilding objectives as well as fishing mortality targets. The ICES framework explicitly allows for review and adaptation, moving from generic approaches to frameworks that are better tailored to the specific characteristics of a resource. For sea bass, as a mixed commercial–recreational fishery with high uncertainty in recreational removals, substantial sectoral diversity, and multiple potentially conflicting objectives set out in the Bass FMP, case-specific harvest rules can better address the full range of FMP objectives while remaining consistent with ICES principles.

Despite the many successes of the ICES MSY Approach, sea bass has specific characteristics that warrant case-specific adaptation. For stocks with high uncertainty and mixed-sector dynamics like bass, recent peer-reviewed research suggests that EQSIM-based F_{MSY} estimates may benefit from additional testing in closed-loop Management Strategy Evaluation (MSE) frameworks that incorporate realistic assessment uncertainty, implementation error, and process variability [3, 17]. Such testing can help ensure that harvest control rules remain robust for stocks with particularly high uncertainty, while the ICES framework's flexibility allows for case-specific adaptation. For bass, with substantial uncertainty in recreational removals and mixed commercial–recreational dynamics, the following case-specific considerations are relevant:

- **Equilibrium assumption**: EQSIM treats biomass as reaching equilibrium in the long-term for a given F, even though dynamics are stochastic [18]. For stocks with high uncertainty like bass, this equilibrium assumption may be less robust given environmental variability, assessment uncertainty, and implementation error. Case-specific MSE testing can help ensure robustness for such stocks.
- **Uncertainty representation**: EQSIM represents uncertainty in natural mortality M and steepness h, but for bass with substantial uncertainty in recreational removals, commercial landings, and stock structure, additional uncertainty sources (structural uncertainties, implementation error, bias in landings and recreational removals) may be important. MSE can explicitly represent these uncertainties to test robustness, which is particularly valuable for mixed commercial–recreational fisheries like bass.
- **Long-term horizon**: The long projection horizon used in EQSIM assumes that equilibrium conditions will be reached and maintained. For bass, where stakeholders and policy makers care about short– and medium–term outcomes, the presence of large fish, and wide spatial availability, shorter-term rebuilding objectives may be more relevant. The ICES framework allows for such case-specific adaptations.
- **Risk–yield asymmetry**: Recent research highlights the strong asymmetry between risk and yield: fishing at roughly $0.6 \times F_{\mathrm{MSY}}$ yields almost the same long-term catch as F_{MSY}, but with a much lower probability of SSB falling below B_{lim} [3]. For bass, with high uncertainty in recreational removals and commercial landings, using F_{MSY} as a strict upper bound rather than a central target may be appropriate, which is consistent with ICES framework flexibility.
- **Multiple objectives**: The ICES MSY Approach focuses on maximum sustainable yield, which is appropriate for many stocks. However, for bass the Bass FMP objectives extend beyond MSY to include social, economic, cultural, and ecosystem objectives. The ICES framework allows for case-specific adaptation, and for bass this means developing harvest control rules that explicitly address these multiple objectives through MSE.
- **Demographic structure**: For bass, where older and larger individuals make a disproportionate contribution to reproductive output, ecosystem value, and recre-

ational value, demographic structure (age and size composition) is particularly important. Spawning stock biomass (SSB) alone may not fully capture reproductive potential if age and size structure are eroded [19, 20]. Preserving large fish may also help mitigate some impacts of warming [20]. For bass, the current management approach's focus on total SSB can be supplemented with explicit consideration of demographic structure, which is consistent with the framework's flexibility for case-specific adaptation.

Precautionary Approach: The ICES MSY Approach provides a robust framework for sustainable fisheries management. Recent research [3], however, suggests that for some stocks with particularly high uncertainty, F_{MSY} values estimated via EQSIM may benefit from additional precautionary testing in closed-loop MSE frameworks. For three of the four benchmarked stocks tested, the probability of $SSB < B_{\text{lim}}$ exceeded 5% when tested in full feedback simulations. This highlights the value of MSE testing for stocks with high uncertainty, such as bass with substantial recreational removals and mixed-sector dynamics, where the ICES framework's flexibility allows for case-specific precautionary adjustments.

The study reveals that EQSIM-based reference-point estimation may under-weight the asymmetry between risk and yield. Long-term yields are almost unchanged (within about 5% of MSY) even if F is reduced to roughly 60% of the nominal F_{MSY}, whereas small upward deviations above F_{MSY} markedly increase probability of falling below B_{lim} [3]. For bass, with high uncertainty in recreational removals and commercial landings, treating F_{MSY} as a strict upper bound rather than a central target may be appropriate, which is consistent with the ICES framework's allowance for case-specific adaptation.

For northern sea bass treating F_{MSY} as an upper limit and exploring lower target F values (e.g. around $0.6 \times F_{\text{MSY}}$) could maintain most of the long-term yield while markedly reducing the risk of $SSB < B_{\text{lim}}$.

Sensitivity to Model Structure and Assumptions: The ICES approach, like all stock assessment methods, is sensitive to model structure, data limitations, and choice of reference-points. Successive benchmarks have led to large shifts in perceived SSB and reference points (Table 1), with recent advised removals more than doubling from 2,432 t to 5,180 t between assessments. While this reflects improvements in assessment methodology and incorporation of new data, it also highlights the value of MSE testing to ensure harvest strategies remain robust across different assessment assumptions and reference point estimates. The ICES framework's allowance for case-specific adaptation means that MSE can be used to develop harvest control rules that are robust to such assessment updates, which is particularly valuable for stocks like bass with high uncertainty.

Multi-Sectoral Dynamics: The ICES MSY Approach provides a robust framework for single-stock management. For sea bass, as a mixed commercial–recreational fishery, commercial discards and recreational removals are both substantial and are currently considered in the advice rule as a single total-removals control. The ICES framework allows for case-specific adaptation to address sector-specific dynamics, and for bass this means developing harvest control rules that can explicitly address sector allocation and sector-specific management needs. Connectivity between assessment units has been incorporated in recent assessments, and ICES explicitly notes that stock structure remains an area of ongoing research, which the framework accommodates through uncertainty representation.

Management Objectives for Bass: The ICES MSY Approach focuses on maintaining biomass that can produce maximum sustainable yield, which is appropriate for many stocks. However, for bass the Bass FMP and Fisheries Act 2020 set out multiple objectives beyond MSY maximisation, including maximising social and economic benefits for coastal communities, ensuring ecosystem health and resilience, protecting demographic population structure, and achieving equitable distribution of benefits across commercial and recreational sectors. The ICES advice rule allows for case-specific review and adaptation, for bass this means developing harvest control rules that explicitly address these multiple objectives.

The ICES MSY rule is conceptually simple (linear reduction of F below $MSY\ B_{\text{trigger}}$) and convenient for tactical advice, and has been applied across many European fisheries. For bass, this evidence base should be interpreted against wider FMP goals, not yield metrics alone. The ICES framework focuses on maximum sustainable yield, which is appropriate for many stocks. For mixed commercial–recreational stocks like bass, with complex spatial structure and strong stakeholder interests, the ICES framework allows for case-specific adaptation. Emerging consensus suggests that for such stocks, reference points and harvest control rules should be tested in closed-loop MSE and that F_{MSY} could be treated as an upper limit within a more conservative control framework, which is consistent with the framework's flexibility [3, 21]. The ICES MSY framework is oriented around maximum sustainable yield, which is appropriate for many stocks. For bass, Bass FMP Goals 5 and 6 emphasise maximising social and economic benefits, coastal community outcomes and ecosystem health. The ICES framework allows for case-specific adaptation, and Section 7 and Section 17 of this review therefore explore alternative objective sets for bass, including large-stock strategies, Maximum Economic Yield (MEY) and Maximum Societal Benefits (MSB), and consider how these could be operationalised and evaluated using MSE within the ICES framework.

2.2 Addressing Uncertainty

The assessment uncertainty and variability highlighted above demonstrate the value of approaches that explicitly represent uncertainty and test management strategies against a range of plausible scenarios, ensuring robustness across different assessment assumptions and reference point estimates.

2.2.1 Ensemble Modelling

Ensemble modelling addresses these limitations by considering multiple alternative model structures and parameter combinations, explicitly representing key uncertainties rather than relying on a single "best" model. The benchmark analysis exploring uncertainties around key parameters like natural mortality (M) and stock–recruitment steepness (h) using likelihood profiles provides valuable insight into data conflicts and the impact of fixed parameters. Given the uncertainties in fixed parameters, recreational catch reporting, and other data inputs, future assessments should further explore ensemble modelling and weighting of alternative hypotheses based on empirical performance [22].

Ensemble approaches can weight models by empirical prediction skill and likelihood, ensuring that management advice reflects the full range of plausible scenarios rather than being overly dependent on a single model specification. This is particularly important for bass, where uncertainties in recreational removals, natural mortality, and stock–recruitment relationships all contribute to substantial uncertainty in reference points and stock status estimates.

The uncertainty grid constructed over M and h during the benchmark could be used to develop ensembles of scenarios for management strategy evaluation, along with hypotheses about implementation of management (e.g. discard and survival rates), or stock structure to provide a more robust foundation for management advice. An ensemble of models can form the basis of the Operating Models for a bass MSE framework that can test alternative harvest control rules, rebuilding strategies, and objective sets (MSY, MEY, LFS, MSB, ESY) under a common treatment of uncertainty.

2.2.2 Management Strategy Evaluation (MSE)

Management Strategy Evaluation (MSE) is a simulation-based framework for testing and comparing alternative harvest control rules (HCRs) before implementation [21]. MSE simulates the complete management cycle: (1) an *operating model* representing the "true" system (stock dynamics, fisheries, environment); (2) an *observation model* simulating data collection and stock assessment with error and bias; (3) a *management procedure* applying the HCR to assessment results to set management measures; and (4) *performance evaluation* comparing outcomes against objectives and reference points.

MSE provides several advantages over traditional reference-point approaches: it explicitly accounts for assessment uncertainty, implementation error, and process variability; it tests how HCRs perform under a range of scenarios rather than assuming perfect knowledge; it can evaluate multiple performance metrics simultaneously (biological, economic, social); and it facilitates stakeholder engagement through transparent, quantitative comparison of alternatives. For mixed commercial–recreational fisheries like bass, MSE is particularly valuable because it can explicitly model sector-specific dynamics, recreational catch uncertainty, and different compliance mechanisms [21]. By testing harvest control rules against ensemble operating models that represent the full range of plausible scenarios, MSE can identify strategies that are robust to uncertainty and less sensitive to assessment updates. This addresses the problems of instability and risk quantification highlighted above, providing a more reliable foundation for management decisions.

MSE is the main central tool for developing and comparing alternative bass harvest strategies in a way that is directly linked to Bass FMP objectives and stakeholder values.

Given the case-specific considerations for bass, alternative frameworks based on proposals by stakeholders may better address the full range of objectives in the Bass FMP. The ICES framework allows for such case-specific adaptation, and these alternatives could be evaluated using MSE within the ICES framework.

2.3 Broader Perspectives

2.3.1 Rebuilding Time-Based Reference Points

Kell et al. [17] propose a risk-equivalent, forward-looking framework as an alternative to MSY, based on rebuilding time rather than equilibrium yield maximisation. B_{rebuild} is defined as the lowest biomass from which a stock can rebuild to target levels within a specified timeframe, replacing static, retrospective thresholds with a biologically grounded, forward-looking metric. This approach may be particularly relevant for bass, where management objectives extend beyond simple catch maximisation to include ecosystem health, social equity, and multi-sector balance. Forward-looking frameworks may better account for uncertainty and provide more transparent risk communication to stakeholders [17].

The use of B_{rebuild} and T_{rebuild} can answer questions such as "how quickly and how reliably will the stock reach a large-stock target biomass under different harvest strategies?", rather than relying solely on asymptotic equilibrium quantities.

Rebuilding policies vary internationally. The United States uses one generation time or time required to rebuild to target when fishing at 0.75 times target fishing mortality, or 2 times minimum rebuilding time (T_{min}) [23]. Australia's harvest policy guidelines suggest rebuild back to limit reference point within T_{min}, with provisions for longer rebuilding based on socioeconomic considerations [24]. The European Union's Common Fisheries Policy calls for rebuilding all commercially-used fish stocks above B_{MSY} without explicitly mandated timelines [25].

2.3.2 Ecosystem-Based Fisheries Management

Ecosystem-Based Fisheries Management (EBFM) takes a holistic overview of all ecosystem elements related to fisheries [26], acknowledging complex interactions by incorporating ecosystem processes and multispecies interactions, accounting for habitat impacts and bycatch, integrating social and economic elements into scientific analysis, facilitating trade-offs between stakeholder priorities, and maintaining ecosystem goods and services. Some EU regional seas management frameworks adopt F targets below F_{MSY} to reduce ecosystem impacts, bycatch, and habitat disturbance [26]. Lower F targets typically reduce catch and profitability but may provide benefits in ecosystem health, biodiversity protection, and long-term resilience.

2.3.3 Integrated Management of Commercial and Recreational Fisheries

Recreational fishers' needs and objectives should be explicitly integrated into management, not treated as residual [27]. Key principles include explicit integration of recreational fishing targets into aquatic ecosystem and fisheries management, formal allocation of catch between sectors based on transparent criteria, variable management approaches implemented at local level, strong institutional frameworks for the recreational sector with clear rights and responsibilities, and adaptive management allowing learning and adjustment as information evolves. Given the substantial recreational component of bass removals, such integrated approaches may better address sector-specific dynamics, incentives, and compliance challenges than current aggregated total-removals controls [28].

2.3.4 Multi-Criteria and Stakeholder-Weighted Approaches

Hybrid frameworks combine biological, ecosystem, and social objectives through multi-criteria decision analysis explicitly evaluating trade-offs between competing objectives (sustainability, profitability, equity, ecosystem health) [29]. Approaches incorporating stakeholder preferences into harvest strategy design through structured decision-making processes may achieve greater stakeholder buy-in and compliance, potentially improving overall management effectiveness [30].

2.4 Potential Alternatives

2.4.1 Current concerns

Management of the northern bass stock focuses on a Maximum Sustainable Yield (MSY) based approach with associated reference points, despite policy goals that explicitly emphasise wider economic, social, and ecological benefits. A first concern is that treating MSY as an operational target rather than a limit risks maintaining spawning-stock biomass (SSB) close to MSY $\mathrm{B_{trigger}}$, leaving little buffer against recruitment variability, climate shocks, and assessment uncertainty, and slowing rebuilding of a stock that is only modestly recovered from past overfishing.

A second concern is that MSY maximises yield, not economic value or coastal welfare, and is known to be inferior to Maximum Economic Yield (MEY) from an economic perspective. Maintaining F at or near F_{MSY} can therefore under-deliver on the FMP's stated goal of maximising benefits to coastal communities. In addition, current measures do not explicitly protect large, old spawners, and the combination of minimum size limits and gear selectivity has historically truncated the age/size structure, reducing resilience, recruitment stability, and recreational fishing quality.

Finally, recreational fisheries are increasingly a major source of value, but are still treated largely as a constraint on a single-species MSY strategy rather than as a resource to be optimised, even though bag limits, seasons, and size limits have clear and sometimes large consequences. Ecosystem and bycatch concerns (cetaceans, seabirds, elasmobranchs, benthic impacts) and climate-driven changes in productivity are also only weakly integrated into the tactical harvest control rule (HCR), raising the risk that advice based solely on single-species MSY reference points will become increasingly misaligned with ecosystem and climate considerations.

2.4.2 Potential alternative objectives

A more coherent set of objectives for a Bass FMP revision would explicitly combine MEY, a Large Fish Strategy (LFS), and broader societal and ecological goals. On the biological side, the primary objective would shift from maintaining SSB above MSY $\mathrm{B_{trigger}}$ to targeting a large, stable stock, for example aiming for biomass on the order of 50–60% of unfished B_0 (or a multiple greater than 1 of B_{MSY} if B_0 is uncertain), and treating F_{MSY} as a limit rather than a target. Economically, an objective could be to maximise the long-run Net Present Value of the fishery subject to conservation constraints, recognising that MEY typically occurs at F below F_{MSY} and biomass above B_{MSY}, and yields higher profits with lower effort and environmental pressure. This would be consistent with achieving a large, stable stock.

Socially, explicit objectives would include maintaining or increasing total recreational welfare (e.g. recreational fisher surplus, defined as the difference between what recreational fishers would be willing to pay for the fishing experience and what they actually pay) and employment in coastal communities, and recognising the high social and economic value of recreational fishing while ensuring a viable, profitable low–impact commercial sector. Ecologically, the objective set would include preserving a broad size and age structure, reducing bycatch and benthic impacts, and incorporating simple ecosystem indicators or ecosystem–informed reference points so that bass exploitation rates remain consistent with ecosystem functioning under climate change.

2.4.3 Potential alternative harvest control rules and measures

Translating those objectives into management could require adapting the current HCR and associated measures. One option is an "MSY-plus" HCR that retains the familiar ICES structure but raises biomass targets and lowers target F. For example, a target biomass B_{target} around 1.5–2 $\cdot\, B_{\text{MSY}}$ and a target fishing mortality F_{target} around 0.7–0.8 $\cdot\, F_{\text{MSY}}$ could be specified, with F_{MSY} as a hard limit. Below B_{lim}, directed commercial fishing would cease and recreational fisheries would be catch-and-release only; between B_{lim} and B_{MSY}, F would ramp up cautiously from zero to a sub-MSY value; between B_{MSY} and B_{target}, F would rise to F_{target}; and above B_{target} fishing mortality would be capped rather than increased further to chase MSY.

Within this stock-wide constraint, the FMP could move from implicit to explicit allocation between sectors. One practical option is to reserve a fixed proportion of allowable removals for the recreational sector (reflecting its higher per-fish value), and to direct the commercial share preferentially to low-impact gears such as hook-and-line while phasing down netting. Recreational-specific sub-rules could be designed around agreed objectives: e.g. maintaining the possibility of retaining at least one bass on most trips for much of the year (as the first retained fish has by far the highest marginal value), and comparing measures such as length of retention seasons and daily bag limits. The FMP could commit to moving from a simple minimum size to a harvest slot (e.g. protecting juveniles below a higher minimum and large, old, fat, fecund female fish (BOFFFFs) above a maximum), with length-based indicators such as L_{95}, L_{max5}, and L_{mega} adopted as formal triggers for tightening or relaxing measures.

2.4.4 Supporting tools and processes

Making these alternatives operational requires small incremental changes to the current advice. A simple age-structured bioeconomic model for bass would allow approximate estimation of F_{MEY} and B_{MEY} for the combined commercial and recreational system, and routine calculation of economic indicators and length-based metrics under candidate regulations. These tools could then be embedded in a formal management strategy evaluation (MSE) framework to compare alternative HCRs and allocation rules against multiple criteria: probability of $SSB < B_{\text{lim}}$, long-run yield, economic returns, recreational welfare, distributional outcomes between sectors, size-structure, and simple ecosystem indicators.

In parallel, the FMP can commit to closing key evidence gaps that limit uptake of MEY, LFS, MSB, and ecosystem-based objectives, including more regular and comprehensive recreational catch/effort data (with size composition and trip costs), better information on discards and post-release survival, improved understanding of spatial structure and recruitment processes, and basic ecosystem and bycatch data needed to derive and apply ecosystem-informed reference points. Taken together, these changes would align the Bass FMP more closely with the broader objectives in fisheries legislation and with stakeholder expectations, while retaining compatibility with existing scientific advice processes and management structures.

2.4.5 Recommendations for Case-Specific Adaptation

The ICES MSY Approach provides a transparent, rule-based link between stock status and catch advice and has been applied across many European fisheries. For bass, evidence of suitability should include social, economic, and ecosystem objectives as well as yield. The ICES framework explicitly allows for case-specific review and adaptation. For bass, as a mixed commercial–recreational fishery with multiple objectives, case-specific considerations include:

1. For stocks with high uncertainty like bass, F_{MSY} estimation via EQSIM may benefit from additional precautionary testing in closed-loop MSE frameworks, with asymmetric risk-yield trade-offs potentially favouring more conservative fishing mortalities [3].
2. Successive bass benchmarks have produced large shifts in perceived stock status and doubled advised catches, primarily due to technical changes in assessment methodology. MSE testing can help ensure harvest strategies remain robust across different assessment assumptions.
3. For bass as a mixed commercial–recreational fishery, case-specific harvest rules can better address sector-specific dynamics, multi-sector catches, and stock connectivity, which the ICES framework allows.
4. The ICES MSY Approach focuses on maximum sustainable yield, which is appropriate for many stocks. For bass, the Bass FMP objectives extend beyond MSY to include economic, social, and ecosystem objectives [2]. The ICES framework allows for case-specific adaptation to address these multiple objectives.

Next steps in the development and implementation of the FMP could include

- F_{MSY} **as upper limit**: Treating F_{MSY} as hard upper bound rather than target, with operational target fishing mortalities set conservatively below F_{MSY} to account for asymmetric risk-yield trade-offs [3].
- **Rebuilding time-based reference points**: Forward-looking frameworks providing more transparent risk communication and potentially better alignment with Bass FMP objectives [17].
- **Management Strategy Evaluation (MSE)**: Full closed-loop simulation testing harvest control rules with explicit treatment of assessment uncertainty, implementation error, and sector-specific dynamics [21].

- **Sector-specific controls**: Explicit allocation and separate management measures for commercial and recreational sectors addressing different dynamics, incentives, and compliance mechanisms [27, 28].
- **Multi-criteria frameworks**: Structured approaches explicitly evaluating trade-offs between sustainability, profitability, equity, and ecosystem objectives with stakeholder engagement [29, 30].

These alternative approaches could be evaluated through stakeholder consultation and quantitative analysis to identify harvest strategies best aligned with Bass FMP goals of long-term sustainability, equitable access, minimised discarding, full compliance, coastal community benefits, and ecosystem protection. Future sections build on these recommendations by (i) reviewing international experience with mixed commercial–recreational fisheries, (ii) identifying a suite of alternative bass harvest strategies (including lower F targets, large-stock strategies, rebuilding-time reference points, sector allocation and MEY-type frameworks), and (iii) outlining the development of a bass-specific MSE to appraise these options against biological, economic, social and ecosystem criteria.]

This review has identified limitations and risks associated with the current ICES MSY Approach for bass, and outlined potential approaches (ensemble modelling, MSE, alternative reference points, integrated commercial–recreational management). This review is extended by conducting a global review of mixed commercial and coastal fisheries to identify examples of how these ideas have been implemented elsewhere. These international case studies provide a range of potential strategies and institutional arrangements that can be evaluated and adapted for UK bass management in light of the Section 1 findings.

3 International Case Studies and Global Alternatives

This chapter answers: What can UK bass management learn from mixed commercial–recreational fisheries elsewhere, and which elements transfer to support Bass FMP and Fisheries Act 2020 objectives? It summarises international practice (allocation, reference points, monitoring, governance) and distils options that can be adapted for UK bass and evaluated through MSE.

This section provides examples worldwide of fisheries management strategies for mixed commercial–recreational stocks, compares these approaches to the current Northeast Atlantic sea bass (*Dicentrarchus labrax*) advice framework, and discusses potential applications to UK bass management. The management of mixed commercial–recreational fisheries is challenging for both fisheries science and policy. Sea bass is a good example, as it supports culturally and economically important fisheries alongside commercial fleets, spans multiple jurisdictions (UK and EU), and suffers from substantial uncertainty in catch estimates, reporting of commercial catches, and the impact of management measures. This review is intended to inform the development of harvest strategies for UK bass management within the Fisheries Management Plan (FMP) framework [2].

3.1 Mgmt Approaches & Alternative Harvest Strategies

Regulatory Context: The international examples span a spectrum from regulation-based systems (bag limits, size limits, seasonal closures) to quota-based allocation frameworks and concession/tourism models. Successful strategies are context dependent. Regulation-based systems offer flexibility and lower data requirements but less precise control over total removals [31, 32]; quota-based systems provide strong control and accountability but require high-quality data and institutional capacity [33]; hybrid systems (e.g. Gulf red snapper) combine IFQs for commercial fleets with seasonal/bag-limit controls for recreational fishers [34].

Sector Allocation: Formal sector allocation is a key difference between systems. Western Australia and New Zealand demonstrate legally specified sector shares that enhance transparency and accountability [33]. In contrast, bass and several other European mixed fisheries generally rely on implicit allocation (commercial quotas and input controls), which can lead to allocation conflict.

Reference Point Frameworks: Reference point frameworks vary across the examples. ICES MSY reference points are used for Baltic cod and bass. Female SSB-based targets and thresholds are used for striped bass [35]. SPR-based reference points underpin aspects of Gulf of Mexico red snapper management [34]. Depletion-based targets are used for New Zealand snapper [33].

Monitoring and Data Systems: Commercial monitoring is generally strong across systems (logbooks, observers, VMS, biological sampling). Recreational monitoring is more variable and often limiting. Survey-based approaches provide statistical rigour but can have high variance and time lags; digital reporting tools can improve timeliness but depend on participation and calibration [36, 37]. Examples such as Western Baltic cod and Western Australia indicate that investment in data systems is crucial for mixed-fishery management [31, 37].

Alternative harvest strategies: Evidence-based alternative harvest strategies that may be relevant to bass include: (i) formal sector allocation; (ii) simulation-optimised bag/slot/season controls; (iii) catch-and-release zones integrated with MPAs; (iv) large-fish protection via slot limits; (v) longer-term MEY-type frameworks where economic data allow; (vi) rebuilding-time-based reference points; (vii) more precautionary F targets within existing MAP flexibility; and (viii) adaptive governance arrangements where compatible with shared-stock management.

3.2 Case Studies (for skimming)

The case studies below illustrate how these management approaches and harvest strategies are implemented in practice. Readers who only need the transferable lessons can skim this subsection.

Western Baltic Cod (*Gadus morhua:*) The Western Baltic cod case study is an example with robust before-after data on the introduction of bag limits in a marine fishery [31]. The regulatory timeline is well documented: a bag limit for recreational fisher of 3–5 cod per day was introduced in 2017, tightened to 2–5 fish in 2020, and further restricted to 0–1 fish per day in 2022, with zero harvest allowed during spawning seasons [31]. These progressive restrictions reflect the severely depleted stock status. Analyses indicate a reduction in removals of approximately 1,722 t in 2017 compared with 900 t predicted by the initial model, underlining the importance of empirical validation and the challenges of modelling recreational fisher behaviour, particularly effort redistribution and compliance [31]. The Haase et al. (2022) study provides a comprehensive simulation framework testing alternative regulation combinations (bag limits, minimum size, slot limits, seasonal closures) and demonstrates how marine recreational fisheries (MRF) data have been integrated into the stock assessment since 2013 [31, 38].

Atlantic Striped Bass (*Morone saxatilis:*) Atlantic striped bass are managed under the Atlantic States Marine Fisheries Commission (ASMFC) across the US East Coast. Amendment 7 (2022) consolidates earlier measures and sets female SSB-based reference points, and recent management has relied on slot limits and bag limits to support rebuilding [35].

Gulf of Mexico Red Snapper (*Lutjanus campechanus:*) Gulf of Mexico red snapper provides an example of contentious mixed fishery management. Amendment 50 devolved aspects of recreational management in federal waters to the Gulf states, with explicit allocations by state [34]. The commercial sector operates under an individual fishing quota (IFQ) programme. Recreational monitoring relies on NOAA programmes such as MRIP (survey-based estimation of recreational catch and effort).

New Zealand Snapper (*Pagrus auratus:*) New Zealand's Quota Management System (QMS) provides a long-established framework with clearly defined reference points and sector allowances [33, 39, 40]. The target biomass is commonly framed as a fraction of unfished biomass, with soft and hard limits, and TACs are allocated among commercial, recreational, and indigenous sectors.

Texas Red Drum (*Sciaenops ocellatus:*) Texas red drum is managed as a recreational-only fishery, with a slot limit, bag limit, and trophy-tag type provisions [32, 41]. Commercial landings are banned. Management relies on regulation-based controls and fishery-independent monitoring.

Western Australia West Coast Demersal Scalefish: Western Australia provides an example of an explicit mixed commercial–recreational management system with formal sectoral catch shares and a combination of commercial and recreational controls. Digital catch reporting tools (e.g. FishCatchWA) have supported improved timeliness of recreational information [37, 42].

Cuban Tropical Sport Fisheries: Cuban flats fisheries for bonefish, tarpon, and permit operate largely within marine protected areas with strict catch-and-release protocols, with access controlled through concessions and tourism models [43, 44, 45].

4 Alternative Strategies

This chapter answers: Which alternative harvest strategies should be considered for bass, how will they be evaluated, and how do the results support Bass FMP and Fisheries Act 2020 objectives? It introduces the evaluation framework (MSE), candidate reference points and HCRs, and the implementation roadmap linking evidence to policy decisions.

This report on the northern stock sea bass stock in ICES divisions 4.b–c, 7.a, and 7.d–h (stock ID bss.27.4bc7ad–h) proposes a framework for evaluating alternative management approaches that address uncertainty, explicitly consider rebuilding dynamics, and the socio–economic and ecosystem objectives set out in the Bass FMP. The ICES framework explicitly allows for review and adaptation, moving from generic approaches to frameworks that are better tailored to the specific characteristics of a resource, and this report proposes such a tailored framework for bass as a mixed commercial–recreational fishery.

Section 1: provided a critical review of the current ICES MSY-based advice framework for UK sea bass and evaluated how well it aligns with Bass FMP goals and relevant international commitments. The work examined stock assessment methodology, reference point estimation, and recent peer-reviewed critiques of the ICES framework.

International lessons (Section 3): summarises how mixed commercial–recreational fisheries operationalise allocation, precautionary control, rebuilding objectives, monitoring, governance, and stakeholder engagement. Those cross-cutting lessons are used here to structure bass-specific alternatives consistent with Bass FMP goals and Fisheries Act 2020 objectives. This chapter then focuses on translating those lessons into candidate bass harvest control rules (HCRs) and evaluating them through MSE.

4.1 Bass Fisheries Management Plan

The Bass Fisheries Management Plan (FMP), developed by the Department for Environment, Food and Rural Affairs (Defra) and the Welsh Government under the Fisheries Act 2020, established a statutory framework for the long-term sustainable management of bass fisheries in English and Welsh waters [2]. The FMP was co-designed through a 2023 stakeholder consultation process and seeks to balance ecological, social, and economic objectives across commercial and recreational sectors.

Section 4.1 sets out the policy goals and decision-relevant framing (including ecosystem and ecosystem-based fisheries management (EBFM) outcomes, and social–equity objectives). Section 4.2 then translates those goals into candidate bass harvest strategies (reference points, HCR logic, and supporting measures) and specifies how those strategies are evaluated through closed-loop MSE against biological, economic, social–cultural, and ecological performance metrics.

This report supports the FMP in these aims by proposing how alternative management strategies can be evaluated. In particular, explicitly for **Goals 5 and 6**:

- **Goal 5**: Maximising social and economic benefits for coastal communities, recreational fishers, and commercial fishers, recognising the substantial contribution of recreational fishing to local economies and the need for equitable distribution of benefits across sectors.

- **Goal 6**: Ensuring ecosystem health and resilience, including protection of demographic population structure (age and size composition), spatial distribution, and broader ecosystem considerations beyond simple biomass targets.

The current ICES MSY-based framework, which forms the basis of existing sea bass advice, is oriented around maximum sustainable yield and does not explicitly address broader social, economic, social–cultural, and ecosystem objectives.

F_{MSY} is problematic as it combines biological and economic considerations in a way that is not always transparent. For example, F_{MSY} could theoretically be infinity if individual cohorts could be harvested once losses due to natural mortality exceed gains from individual growth. F_{MSY} and B_{MSY}, therefore, are not fixed biological quantities but depend on how removals are distributed across fleets and sectors. This allocation (commercial vs. recreational, different gear types) may change with shifts in fishing effort between sectors and factors such as relative stability (the historical allocation keys used in EU fisheries management), and sector-specific management measures. Furthermore, F_{MSY} does not explicitly account for size structure: it focuses on maximising total yield without considering the demographic composition of the stock (the proportion of large versus small fish), which is critical for stock resilience, reproductive potential, and stakeholder objectives such as maintaining large individual fish for recreational angling and higher-value commercial catches. These limitations—the dependence on sector allocation and the neglect of size structure—undermine the interpretation of MSY as a universal management target.

This report addresses these gaps by:

1. Proposing a multi-objective harvest strategy that can be evaluated against biological, economic, social–cultural, and ecological objectives, directly supporting FMP Goals 5 and 6.

2. Incorporating sector-specific considerations that recognise recreational fishing as a key stakeholder and objective, addressing the FMP's emphasis on equitable access and distribution of benefits.

3. Using explicit biomass targets and rebuilding-time-based reference points that provide transparent, stakeholder-relevant outcomes (e.g. "rebuild to B_{target} with robust size and age structure (Large Fish Strategy) within X years") rather than abstract long-term equilibrium quantities.

4. Providing a Management Strategy Evaluation (MSE) framework that can test candidate harvest strategies against a range of potentially conflicting objectives, enabling evidence-based selection of management approaches.

5. Outlining an implementation roadmap that supports an adaptive management approach, with phased development allowing for stakeholder engagement, data collection, iterative refinement, and continuous learning from MSE results and monitoring data.

The candidate alternative approaches proposed for evaluation are designed to be consistent with FMP objectives, including sustainability, precautionary management, ecosystem protection, use of scientific evidence, bycatch minimisation, equal access, national benefit, and climate change mitigation as set out in the Fisheries Act 2020. By moving beyond a narrow MSY focus to explicitly incorporate social, economic, and ecosystem objectives, these candidate approaches provide options for a more complete response to the FMP's vision of balanced, multi-sectoral sea bass management that serves the diverse interests of coastal communities, recreational fishers, commercial fishers, and the wider public.

4.2 Alternative Management Strategies

This section proposes a framework for evaluating alternative management strategies that could replace the current ICES MSY-based framework [e.g. 46, 47]. The framework is designed to respond directly to Bass FMP Goals 5 and 6 and to support management decisions on how alternative harvest approaches may affect social and economic benefits, efficiency, profitability, and sustainability for the bass fishery and its stakeholders. Candidate approaches explicitly address diverse targets, rebuilding time, demographic population structure (age and size composition), spatial distribution, and socio–economic objectives for coastal communities and the recreational sector. For clarity, in this report a "large, resilient stock" means not only high biomass, but also robust demographic structure, including a high proportion of older, larger, more fecund individuals.

The proposal is based on recent findings [3, 17], and on evidence that spawning stock biomass (SSB) alone is not necessarily a robust proxy for reproductive potential if age and size structure are eroded [19], that explicit age–based indicators can and should be used to track the contribution of older fish to stock status [48], and that spatial indicators may contain additional, complementary information on depletion and recovery dynamics [49]. For example, the Age-Based Indicator for MSY (ABI_{MSY}) quantifies the contribution of older fish to stock status by comparing current age structure with the equilibrium age structure at B_{MSY}.

[3] demonstrated that the current ICES MSY-based framework is not necessarily precautionary and may under-protect depleted stocks. Fishing at or below F_{MSY} has not consistently translated into biomass, rebuilding, or structural outcomes aligned with EU and UK policy objectives. Simulation-tested alternatives may therefore be more suitable for sea bass. The current framework targets maximum sustainable yield, but does not explicitly target maximisation of social and economic benefits, delivery of Good Environmental Status (GES), or alignment with the expressed preferences of key stakeholder groups (small-scale commercial fishers, recreational fishers, recreational businesses, and the wider public).

Alternative approaches proposed for evaluation should explicitly consider broader Bass FMP Goals 5 and 6. To do this requires clarification about the ICES framework. Two questions need to be resolved about compatibility between the ICES framework and the proposed approach.

ICES Framework:

1. **Alternative HCRs**: Can the MSE framework be used to evaluate alternative harvest control rules (e.g. rebuilding-time-based rules, Large Fish Strategy variants, sector-specific rules), or must it simply tune the control parameters of the existing ICES MSY Advice Rule (e.g. adjusting F_{target} or $MSY\ B_{\text{trigger}}$ values)? The ICES guidelines state that "the HCR applied during the MSE should be the same rule used by ICES to provide advice," which could be interpreted either way. This framework proposes testing alternative HCR structures, with the understanding that any selected strategy would become the formal ICES advice rule for sea bass.

2. **Objectives beyond MSY**: Will ICES allow evaluation of objectives beyond MSY (e.g. Maximum Economic Yield (MEY), Large Fish Strategy (LFS), Maximum Societal Benefits (MSB), Ecologically Sustainable Yield (ESY)), or must all procedures demonstrate strict MSY-consistency? The ICES guidelines require strategies to be "consistent with the MSY approach," but it is unclear whether this means:

    - **Strict interpretation**: All procedures must achieve MSY or better, with objectives beyond MSY requiring explicit policy justification outside the ICES advice framework.
    - **Flexible interpretation**: Procedures can target objectives beyond MSY (e.g. MEY, LFS, MSB) provided they also meet the precautionary criterion ($P(SSB < B_{\text{lim}}) < 5\%$) and can demonstrate MSY-consistency as a co-benefit (e.g. achieving MSY or higher biomass while also meeting other objectives).

Alternative Approach: proposes testing HCR structures and evaluating objectives beyond MSY, based on the interpretation that:

- ICES guidance that MSE can be used to "evaluate and select a management strategy that is robust to uncertainty instead of focusing on identifying a single preferred assessment model" supports testing alternative HCR structures within the benchmark process.

- The Bass FMP Goals 5 and 6 and Fisheries Act 2020 provide explicit policy justification for objectives beyond MSY, particularly for maximising social and economic benefits and ensuring ecosystem health.

- All candidate procedures can be tuned to meet the ICES precautionary criterion ($P(SSB < B_{\text{lim}}) < 5\%$), and procedures targeting objectives beyond MSY will either demonstrate MSY-consistency or be presented with clear policy justification.

Resolution of these questions requires dialogue with ICES during the benchmark process. If ICES requires the narrower interpretation (parameter tuning only, strict MSY-consistency), the framework can be adapted accordingly while still addressing Bass FMP objectives through parameter choices and supporting management measures.

4.2.1 ICES MSY Approach: Bass Implications (Policy Summary)

ICES derives reference points for F_{MSY} and the associated biomass thresholds using EQSIM in the benchmark process, and then applies a generic MSY advice rule. For bass, the policy-relevant implication is that EQSIM-based precautionary reference points can fail to remain precautionary once the full closed-loop feedback between assessment, advice, implementation and population dynamics is represented, especially with substantial uncertainty in recreational removals and mixed-sector behaviour [3]. Technical details of the EQSIM/precautionary logic and how reference points are interpreted are provided in Appendix J.

For bass specifically, this motivates treating F_{MSY} as a precautionary ceiling rather than a central target, and prioritising explicit rebuilding-time and structural objectives (e.g. Large Fish Strategy outcomes), so the approach can deliver the biomass, age/size composition, and stakeholder-relevant recovery trajectories required by the Bass FMP and Fisheries Act 2020.

4.2.2 Management Objectives

Stakeholder consultation and recent external reviews indicate that sea bass management objectives need to be broadened beyond a narrow MSY focus to include economic, social–cultural and ecological dimensions. In addition to conventional biological objectives (e.g. maintaining biomass above B_{MSY} and avoiding B_{lim}), objectives include:

Alternative Objectives

- **Large Fish Strategy (LFS):** maintaining robust demographic population structure (age and size composition) with a high proportion of large, old fish to deliver high catch per unit effort (CPUE), more and larger fish, and greater resilience to environmental shocks. LFS focuses on *large individual fish* (size/age structure), not total biomass, though maintaining large fish may result in higher total biomass as a consequence. Operationalising LFS requires explicit size and age structure targets (e.g. ABI_{MSY}-type metrics), harvest rules that keep F well below F_{MSY} to protect large fish, and management measures such as slot limits or maximum size limits. See Section 4.2.2 and Appendix D for detailed implementation guidance.

- **Maximum Economic Yield (MEY):** maximising the discounted net present value of profits from the sea bass fishery. MEY-based targets typically imply lower fishing mortality and higher biomass than MSY, with associated gains in resilience and demographic population structure. Implementing MEY requires bioeconomic models that integrate cost and price data with stock dynamics for both commercial and recreational sectors. For mixed commercial–recreational bass, MEY is aspirational/long-term and currently constrained by economic data; we are using "MEY-type thinking" as a lens rather than proposing an immediate MEY control rule. See Section 4.2.2 for further discussion.

- **Maximum Societal Benefits (MSB):** maximising the total social and economic value generated by the sea bass stock across commercial and recreational sectors, rather than yield. This requires indicators such as Gross Value Added (GVA) and Fishery Performance Indicators (FPIs), with optimal stock size and fishing mortality chosen to maximise aggregate social welfare subject to ecological constraints.

- **Ecologically Sustainable Yield (ESY):** ensuring that bass fishing mortality and biomass levels are consistent with wider ecosystem objectives (e.g. Good Environmental Status (GES), biodiversity conservation, climate resilience). ESY-type objectives imply F targets below F_{MSY} and explicit consideration of bycatch, habitat impacts, trophic interactions and climate-driven changes in productivity.

These alternative objectives are not mutually exclusive: for example, an LFS that maintains a high proportion of large individual fish and robust age/size structure may simultaneously support MEY- or MSB-type outcomes, while also contributing to ESY.

Total biomass vs. large individual fish

Stakeholders may value large individual fish for different reasons (higher prices, trophy fishing, reproductive benefits) than they value total biomass.

- **Total biomass (SSB)**: The total weight of all fish in the spawning stock. A stock can have high total biomass but be dominated by small, young fish (poor size/age structure).

- **Large individual fish (size/age structure)**: The proportion of large, old fish in the population. A stock can have many large individual fish even if total biomass is moderate, or it can have high total biomass but few large fish.

The key implication for bass is that candidate harvest strategies should be evaluated against a suite of biological, economic, social–cultural and ecological performance metrics (quantitative measures used to assess how well management strategies achieve their objectives), using MSE to explore trade-offs and identify strategies that are robust under uncertainty and acceptable to stakeholders.

Large Fish Strategy: The Large Fish Strategy (LFS) is defined in the "Alternative Objectives" box above (Section 4.2.2). A LFS aims to conserve a high proportion of big, old bass in the population, recognising that these fish contribute disproportionately to reproduction, stock resilience, and the quality of recreational fishing. The LFS can be represented in harvest control rules by linking exploitation rates to explicit structural indicators (e.g. ABI_{MSY}, proportion of biomass above a reference length) alongside biomass targets. Management tools include harvest slots, maximum size limits, spatial protection measures, and gear regulations that reduce fishing mortality on the largest individuals. Within the MSE framework, alternative LFS designs can be tested by comparing scenarios with and without LFS measures, by comparing how well objectives are met using performance metrics. This allows trade-offs to be evaluated. A LFS may provide benefits for the recreational sector through increased trophy fish availability, stable high-quality recreational fishing opportunities, and enhanced local economic value. For detailed implementation guidance, see Appendix D.

Maximum Economic Yield: Maximum Economic Yield (MEY) is defined in the "Alternative Objectives" box above (Section 4.2.2). MEY seeks to maximise the discounted net present value of profits from the sea bass fishery, recognising that economic efficiency may require different fishing mortality and biomass targets than those that maximise yield. For mixed commercial–recreational fisheries like bass, MEY presents both opportunities and challenges. While MEY is well-established for single-sector commercial fisheries, its extension to mixed commercial–recreational fisheries remains largely theoretical. International case studies (e.g. Australian Commonwealth fisheries, Western Australia state fisheries) demonstrate MEY as a primary economic objective for commercial fleets and qualitative consideration of economic efficiency in allocation decisions, but no well-documented case exists where a mixed commercial–recreational coastal fishery is explicitly managed to a formal joint MEY reference point that incorporates both sectors' net benefits in a single harvest control rule [50, 51, 52]. For bass, MEY is aspirational/long-term and currently constrained by economic data; we are using "MEY-type thinking" as a lens rather than proposing an immediate MEY control rule. A fully specified "joint MEY" control rule would be a longer-term development requiring enhanced economic data and stakeholder engagement. See also Section 4.2.2 for further discussion.

4.2.3 Current Reference Points

A benchmark based on SS3 was conducted in2025[53, 54]. The F–based MSY and precautionary reference points (F_{MSY}, F_{PA}) were re–estimated using EqSim, while B_{lim}, B_{PA}, and thus MSY B_{trigger} were derived from the SS3 SSB and recruitment time series using standard ICES formulas [46, 55]. F_{MSY} is estimated at 0.170 from EqSim and is set equal to F_{PA}, defined as the fishing mortality that ensures $SSB \geq B_{\mathrm{lim}}$ with 95% probability.

B_{lim} (15 666 t) is defined as the average of the three lowest spawning–stock biomass values in the time–series that are associated with above–median recruitment, while B_{PA} is computed as $B_{\text{lim}} \times \exp(1.645\sigma)$ using the variance in the terminal assessment year, giving $B_{\text{PA}} = \text{MSY } B_{\text{trigger}} = 19\,339$ t [7, 8]. Under the Western Waters multiannual plan, MAP B_{lim}, MAP MSY B_{trigger} and MAP F_{MSY} are set equal to these ICES reference points, with an F_{MSY} range from 0.145 to 0.170 that results in no more than a 5% reduction in long–term yield compared with MSY [56, 54].

The ICES Working Group on Benchmark for Sea Bass (WKBSEABASS) for northern and southern sea bass identified problems with the MSY-based reference points [11, 57]. Retrospective and hindcasting diagnostics for sea bass revealed substantial instability in terminal–year SSB estimates, such that successive assessment updates could move the stock estimate above or below MSY B_{trigger} purely because of noise, risking unnecessary or erratic management action if MSY B_{trigger} is used as the primary decision threshold [57]. Likelihood profiles over natural mortality and stock–recruitment steepness showed that the fitted production function, and hence F_{MSY} and B_{MSY}, are highly sensitive to fixed parameter choices and to conflicts between age/length composition, survey indices and catch data [57]. This implies that there is no single, well–determined MSY regime for bass; instead, multiple plausible model configurations exist, each with different MSY reference points. The benchmark therefore recommended defining an explicit biomass target B_{MSY} above MSY B_{trigger} for bass, exploring ensembles of assessment models rather than a single "best" model, and basing advice on models that demonstrate adequate prediction skill against withheld data, rather than on EqSim–derived point estimates of MSY reference points alone [57].

Implication for interim targets. The MAP F_{MSY} range of 0.145–0.170 is, by construction, a "pretty good yield" range: all values within the range are defined to entail no more than a 5% loss in long–term yield relative to MSY. We therefore propose $F = 0.145$ as the interim, MAP-consistent operational choice while MSE is developed. In parallel, MSE will explicitly evaluate alternatives such as $0.6 \times F_{\text{MSY}}$; recent EQSIM–MSE analyses indicate this level can retain near-MSY long-term yield while materially reducing risk of breaching B_{lim} [3, flat–topped yield curve]. The bass–specific magnitude of these risk–yield trade-offs will be quantified in the proposed MSE.

The ICES framework has been applied across many European fisheries. For bass, performance needs to be judged against the broader Bass FMP objective set, not MSY-oriented outcomes alone. For bass, as a mixed commercial–recreational fishery with specific characteristics, case-specific considerations include: (i) the use of hockey–stick stock–recruitment relationships, which for some stocks may produce biomass limits and triggers that are not risk–equivalent across stocks [17, 3]; (ii) the focus on SSB as a proxy for reproductive potential, which for bass may benefit from explicit consideration of age and size composition given the disproportionate contribution of older, larger fish [19]; and (iii) the long–term equilibrium orientation, which for bass may be supplemented with explicit control over rebuilding timeframes and attention to demographic and spatial structure [17, 49].

These case-specific considerations have motivated alternative approaches that can complement the ICES framework, including rebuilding–based reference points (B_{rebuild} and T_{rebuild}) that explicitly characterise recovery trajectories [17], age–based indicators (ABI_{MSY}) that track the contribution of older fish to stock status [48], and spatial indicators that provide early warning of depletion [49]. For sea bass, where older and larger individuals make a disproportionate contribution to reproductive output, ecosystem value, and recreational value, and where availability along the coast is central to local communities, these alternative approaches are particularly relevant. The ICES MSY Approach's focus on long–term equilibrium targets is appropriate for many stocks, but for bass the FMP objectives also include short– and medium–term outcomes, presence of large fish, and wide spatial availability that stakeholders and policy makers care about. The ICES framework allows for case-specific adaptation to address these objectives. Detailed discussion of these case-specific considerations and alternative approaches is provided in Appendix J.

4.2.4 Alternatives for Sea Bass

The ICES MSY Approach has been applied across many European fisheries. For bass, with mixed-sector objectives and higher uncertainty, case-specific testing is needed to show policy performance. For bass, as a mixed commercial–recreational fishery with multiple objectives, case-specific harvest rules can better address the full range of FMP objectives. The ICES framework allows for such case-specific adaptation, and this subsection outlines the key approaches available for evaluating alternative management strategies for bass.

Management Strategy Evaluation (MSE): Management Strategy Evaluation provides a framework for testing alternative harvest control rules. For sea bass, the Operating Model can be conditioned on the existing analytical assessment, including both commercial and recreational removals [e.g. 11, 57], and used in closed-loop simulations to evaluate the current ICES MSY advice rule against candidate bass-specific HCRs. The MSE framework can be configured to address multiple, potentially competing objectives (e.g. MSY, MEY, Large Fish Strategy (LFS), Maximum Societal Benefits (MSB)) and to quantify trade-offs among these, using forecast horizons that are consistent with the uncertainty in the system, rather than relying on idealised long-term (150–200 year) projections [58, 59]. Two MSE configurations are available:

Full management procedure (MP) MSE: In a full MP MSE, the feedback loop between stock dynamics, data collection, assessment, advice, and implementation is represented explicitly within the simulation framework. The assessment model is rerun at each assessment interval using simulated data, and the resulting estimates are passed through the agreed harvest control rule (HCR) to generate management advice. This configuration allows the performance of candidate MPs to be evaluated under realistic uncertainty in both the observation and estimation processes, as well as in implementation, and is therefore the preferred approach when computationally feasible and when the assessment model is sufficiently well established. However, a challenge arises when advice is based on a complex assessment procedure like SS3, which would need to be simulated at each step in the MSE loop, making the approach computationally intensive.

Short-cut MSE: Short-cut management strategy evaluations retain the structure of the benchmark assessment model, while avoiding the need to rerun a full assessment within the simulation loop, by emulating the feedback between assessment, advice, implementation, and stock dynamics (e.g. as implemented in the Reference Point Estimation Tool, RPETool). These approaches can be used to re-estimate effective F_{MSY} and $F_{P.05}$ and to evaluate alternative HCRs under realistic uncertainty [3, 60, 59]. In the short-cut configuration, the estimation step in the loop is replaced either by (i) an assessment module that applies the same estimator as in the benchmark assessment, or (ii) an emulator that approximates the statistical properties of the estimator by adding appropriate error to the quantities used in the HCR [58].

Empirical management procedures: Empirical MPs use harvest control rules that link management advice directly to observed indicators (e.g. survey indices, catch rates, length composition) without requiring a full stock assessment at each management cycle [e.g. 61]. These procedures are particularly useful when: (i) complex assessment models like SS3 are computationally prohibitive to run within an MSE framework; (ii) data are insufficient for full assessments but sufficient for indicator-based rules; (iii) rapid, transparent decision-making is prioritised; or (iv) the relationship between indicators and stock status is well understood and stable. For sea bass, empirical MPs could be based on indicators such as commercial and recreational catch per unit effort (CPUE/LPUE), survey biomass indices, mean length in catches, or age-based indicators (e.g. ABI_{MSY}), with HCRs that adjust fishing mortality or catch limits based on these indicators relative to reference levels. Empirical MPs are computationally efficient, transparent, and can be robust to assessment uncertainty, but they require careful calibration to ensure they meet precautionary criteria and may be less information-rich than assessment-based approaches. The MSE framework can be used to test and tune empirical MPs to ensure they perform well across a range of uncertainties and meet management objectives.

In the ICES guidelines, a full MP MSE is generally preferred where the benchmark assessment is stable, computational resources are sufficient, and the results are intended to underpin long-term, precautionary management decisions [e.g. 58, 59]. Short-cut MSE configurations can be used as a pragmatic alternative when the repeated fitting of complex assessment models is not feasible, or as an intermediate step to screen candidate harvest control rules and operating model configurations before developing a full MP MSE [60, 3]. Empirical MPs offer a third option that can be particularly valuable when computational constraints or data limitations make assessment-based approaches challenging, while still allowing rigorous testing through MSE. In all cases, care is needed to ensure that the sources of uncertainty most relevant to the management objectives are adequately represented in the chosen configuration.

Rebuilding-Based Framework: The rebuilding-based framework allows the definition of stock–specific biomass reference points and HCRs that are explicitly linked to rebuilding time [17]. For sea bass we propose to:

1. define an explicit biomass target B_{target} (at least B_{MSY}, and possibly higher to reflect ecosystem and recreational objectives);

2. calibrate B_{rebuild} and T_{rebuild} for sea bass using the benchmark assessment and appropriate life–history parameters, such that B_{rebuild} represents the lowest biomass from which the stock can rebuild to B_{target} within an agreed T_{rebuild} under a specified rebuilding fishing mortality F_{rebuild}; and

3. design bass HCRs that (i) treat F_{MSY} as an upper bound rather than a target, (ii) use lower target fishing mortalities (e.g. $\approx 0.6 \times F_{\mathrm{MSY}}$) that retain most of the long–term yield while reducing risk [3], and (iii) incorporate explicit rebuilding clauses that reduce F to F_{rebuild} when $B < B_{\mathrm{rebuild}}$ until the stock has demonstrably recovered to B_{target} or T_{rebuild} is back within the agreed horizon.

Integration and Evaluation: A full MSE is expected to be more precautionary and to offer more transparent control over rebuilding trajectories than the current ICES MSY-based framework [3, 17]. Combined with structural indicators such as ABI_{MSY} that explicitly track the presence of older fish [48], the insights on SSB and reproductive potential from Kell et al. [19], and spatial indicators of depletion and recovery [49], this makes these approaches suitable candidates for evaluation for sea bass.

Given the multiple plausible combinations of natural mortality, stock–recruit steepness, recreational removals and spatial stock structure (single stock vs meta-population connectivity) identified for bass, and the multi-criteria nature of the Bass FMP, MSE should be viewed as a key tool for evaluating alternative harvest approaches. Ensembles of Operating Models representing key uncertainties can be combined with alternative objectives (MSY, MEY, LFS, MSB, ESY) to evaluate how candidate harvest control rules perform not only in terms of traditional biological risk metrics (e.g. probability of $B < B_{\text{lim}}$), but also in terms of CPUE, GVA, distribution of benefits between sectors, and ecosystem indicators.

4.2.5 Mixed Commercial–Recreational Fisheries

Alternative management approaches have been adopted for mixed commercial–recreational fisheries, and have several common elements

Combination of multiple management tools: rather than relying on any single lever. Total Allowable Catches (TACs), formal allocation between sectors, bag and size limits, seasonal and area closures, gear restrictions, and technical measures to reduce bycatch and improve discard survival are routinely used in combination.[17] In several cases (e.g. Atlantic striped bass, Gulf of Mexico red snapper, Western Australia demersal scalefish) structured stakeholder processes and advisory councils play a central role in setting objectives, reviewing performance, and adapting measures.

Explicit allocation between commercial and recreational sectors: is common where both sectors are important, although the formality and legal status of allocation varies widely. Examples range from quota shares defined in legislation (e.g. some US and Australian fisheries) to more informal or periodically revisited allocation guidelines.[17] In most cases, allocations are informed by some combination of biological, economic and social considerations, although fully integrated bioeconomic or MEY-based harvest control rules remain rare. For bass, this does not imply a quota-only model: while quota tools can improve accountability in some contexts, poorly designed systems can concentrate access rights, weaken low-impact/small-scale participation, and fail to reflect gear-specific impacts on stock structure and coastal communities.

Move beyond simple MSY-based objectives: towards frameworks that incorporate economic efficiency, social outcomes and ecosystem considerations. Examples include precautionary buffers below F_{MSY}, large-fish protection via slot limits, rebuilding time-based targets, and, in some jurisdictions, MEY as a primary economic objective for commercial fleets. However, there is no well-documented case where a mixed commercial–recreational coastal fishery is managed to a formal joint MEY reference point that explicitly integrates both sectors' net benefits in the harvest control rule.

For bass, these case studies suggest that:

- formal sector allocation, large-fish protection, and more precautionary F targets are feasible near-term options;
- rebuilding time-based reference points and explicit ecosystem considerations provide a coherent way to link harvest strategies to Bass FMP and Fisheries Act objectives; and
- MEY-type and multi-criteria approaches are promising longer-term directions, but will require improved economic and social data, and development of MSE frameworks that can evaluate trade-offs across objectives.

Stakeholders:

Note: This section is preliminary and will be updated based on ongoing stakeholder consultation and feedback. The positions summarised below are informed by both the stakeholder review material and internal supporting studies (e.g. *Alternative management objectives*, *Maximum Sustainable Yield – the wrong management objective for bass*, Tidbury et al. (2021), Cevnini (2023), and Andrews (2021) on economic considerations).

Concerns with the current ICES MSY, and with any future approach, is that they may rely primarily on MSY-based reference points alone. These raises both technical issues (how MSY reference points are derived and used) and governance issues (alignment with the Fisheries Act 2020, the Joint Fisheries Statement, and the Bass FMP goals), and requires a broader multi-objective framework for sea bass.

- The ICES MSY Approach focuses on maintaining a biomass that can produce maximum sustainable yield, which is appropriate for many stocks under yield-focused objectives. For bass, the FMP objectives extend beyond MSY to include social, economic, social–cultural, and wider ecological objectives such as maximising benefits for coastal communities, protecting cultural and recreational values, and mitigating ecosystem impacts. The ICES framework allows for case-specific adaptation, and international examples from Canada, the USA and New Zealand demonstrate how biological, social–cultural, economic and ecological objectives can be explicitly combined in fisheries management plans, even if data limitations mean that some human-dimension targets remain qualitative. For bass, case-specific harvest rules can better address the complete set of legal and policy objectives set out in the Fisheries Act 2020, the Joint Fisheries Statement, and the Bass FMP.
- Inequality and sectoral disenfranchisement under an MSY framework that optimises yield without regard to who benefits. Recreational fishing now accounts for a large share of bass removals and is estimated to generate substantial gross value added (GVA) to coastal economies, yet in current ICES advice recreational interests are treated as a residual component in a single total-removals constraint rather than as a primary objective in their own right. To take into account such concerns a revised harvest approach must (i) acknowledge recreational fishing as the largest stakeholder

by numbers and, arguably, by social and economic contribution per tonne landed, (ii) ensure that recreational and small-scale commercial sectors are not disadvantaged by reference points calibrated on commercial-yield objectives alone, and (iii) adopt explicit size and age structure targets and rebuilding timelines that support a Large Fish Strategy (LFS) with more and bigger bass, higher CPUE/LPUE, and improved recreational fishing experience, rather than merely maximising biomass-weighted yield.

- The way in which uncertainty is handled within the ICES MSY framework. EQSIM currently fixes key biological parameters (e.g. natural mortality, stock–recruit steepness), does not represent important sources of uncertainty (e.g. in recreational removals, small-scale commercial catches, discards), and evaluates precautionary criteria over very long horizons, leading to reference points that can appear precise but are underpinned by strong and often opaque assumptions. For bass in particular, stakeholders identify major data gaps in recreational catch and effort, social and cultural values, climate effects on productivity and distribution, and bycatch of non-target species, and they argue that moving beyond an MSY-based harvest approach requires a clearer roadmap for data collection and for integrating these data into assessment and management.

- A set of preferred directions for future bass management include (i) moving away from treating F_{MSY} as an optimised target and instead either discarding it altogether or using it only as an upper bound within more conservative rebuilding rules; (ii) adopting explicit biomass targets and rebuilding timeframes (e.g. based on B_{rebuild} and T_{rebuild}) with a higher probability of achieving those targets in the short to medium term; (iii) developing harvest approaches that explicitly account for social, economic and ecological performance, for example via MEY, Large Fish Strategy (LFS), Maximum Societal Benefits (MSB) and Ecologically Sustainable Yield (ESY) type objectives and associated indicators (GVA, Fishery Performance Indicators, length-based indicators, ecosystem-informed fishing mortality); and (iv) using ensemble modelling and Management Strategy Evaluation (MSE) as the main tools for testing candidate harvest approaches against multiple objectives and sources of uncertainty, including sector-specific performance and equity considerations, before selecting a final strategy.

4.2.6 Framework

Drawing together the reviews of the ICES approach and those in use globally, and stakeholder feedback, a framework is proposed *for evaluation in Management Strategy Evaluation (MSE)*, not as adopted policy. It is intended to address the specific characteristics of bass as a mixed commercial–recreational fishery while explicitly targeting Bass FMP Goals 5 and 6 and the broader objectives of the Fisheries Act 2020 [2], recognising that the ICES framework allows for case-specific review and adaptation. The approaches are designed to be evaluated and refined through MSE before any final strategy is agreed and implemented.

Core principles: The alternative strategy is built on six core principles:

1. **Precautionary and risk-based**: Treat F_{MSY} as an upper bound rather than a target, use lower operational fishing mortalities (e.g. $\approx 0.6 \times F_{\text{MSY}}$ or the recommended operational target at the lower end of the MAP range, e.g. $F \approx 0.145$) that retain most long-term yield while substantially reducing risk, and explicitly represent uncertainty through ensemble Operating Models.

2. **Explicit rebuilding objectives**: Define clear biomass targets (B_{target}) and rebuilding timeframes (T_{rebuild}), with harvest control rules that ensure a high probability of achieving these targets within agreed horizons. Use rebuilding-based reference points (B_{rebuild}) to structure decision-making rather than relying solely on equilibrium MSY quantities.

3. **Multi-objective evaluation**: Evaluate candidate harvest strategies against a basket of biological, economic, social–cultural and ecological performance metrics, recognising that maximising yield is not the sole objective. Use MSE to explore trade-offs between MSY, MEY, Large Fish Strategy (LFS), Maximum Societal Benefits (MSB), and Ecologically Sustainable Yield (ESY) objectives.

4. **Structural and spatial considerations**: Incorporate age-based indicators (e.g. ABI_{MSY}) and spatial indicators alongside SSB to track reproductive potential, resilience, and distribution. Design harvest control rules that protect large fish and maintain spatial availability along the coast.

5. **Sector integration**: Acknowledge the diversity of stakeholders within both commercial and recreational sectors. Within the commercial sector, this includes small-scale targeted fishers (hooks & lines with historical authorisations), bycatch fishers (trawlers, seiners), and different gear types, all of whom will benefit from management that maintains a large, resilient stock (high biomass plus a strong proportion of older, larger, more fecund fish) in the UK through higher catch rates, better prices (for large fish), and reduced fuel costs. Recognise recreational fishing as a key stakeholder and objective, not a residual component. Consider formal sector allocation, sector-specific management tools, and performance metrics that explicitly track benefits to different commercial sub-sectors and recreational sectors separately.

6. **Adapt and learn**: Implement an adaptive management approach where the framework is iteratively refined based on MSE results, stakeholder feedback, monitoring data, and emerging evidence. Establish regular review cycles to update the MSE framework with new data, refine management procedures based on performance, and adapt to changing conditions (e.g. climate, markets, stakeholder priorities). Frame uncertainty and learning as integral to the decision-making process rather than barriers to action.

Harvest Control Rules:

Candidate rules a *framework for evaluating* alternative management approaches, not a final strategy, is proposed. The candidate harvest control rules are designed to be tested through Management Strategy Evaluation (MSE) before agreement on implementation. This allows stakeholders to:

- Compare multiple options transparently using quantitative performance metrics
- Understand trade-offs between different objectives (biological, economic, social, ecological)
- Build consensus on a preferred strategy based on evidence rather than assumptions
- Refine and adapt rules based on MSE results and stakeholder feedback

The final strategy will be selected through a structured decision-making process informed by MSE results, stakeholder priorities, and policy objectives.

Candidate harvest control rules for sea bass combine rebuilding-time-based reference points with more precautionary fishing mortality targets and explicit biomass objectives. A candidate rule may work as follows:

1. **Biomass target**: Define B_{target} at least B_{MSY} and potentially higher (e.g. $1.2\,B_{\text{MSY}}$) to support high CPUE, large fish availability, and ecosystem resilience. This target should be explicitly stated in terms of both SSB (total biomass) and demographic structure indicators (e.g. proportion of fish above a characteristic size threshold, ABI_{MSY}).

   Biomass target vs. Large Fish Strategy (LFS) are separate objectives:

   - **Biomass target (B_{target})**: Aims for a specific total biomass (SSB). This could be achieved through many small fish OR fewer large fish—the target does not specify size structure.
   - **Large Fish Strategy (LFS)**: Aims for a high proportion of *large individual fish* (robust size/age structure), regardless of total biomass. LFS requires explicit size and age structure targets (e.g. minimum proportion of large fish, ABI_{MSY} thresholds) to ensure the stock has many large individual fish, not just high total biomass.

   These objectives should be pursued together (e.g. achieve B_{target} *with* robust size/age structure), but they are conceptually distinct. A stock could meet a biomass target but fail LFS objectives if it is dominated by small fish. Conversely, a stock could meet LFS objectives (many large fish) even if total biomass is moderate.

2. **Rebuilding reference points**: Calibrate B_{rebuild} and T_{rebuild} for bass using the benchmark assessment, such that B_{rebuild} represents the lowest biomass from which the stock can rebuild to B_{target} within an agreed timeframe (e.g. one generation time, or 5–10 years) under a specified rebuilding fishing mortality F_{rebuild} (e.g. $0.6 \times F_{\text{MSY}}$ or the recommended operational target at the lower end of the MAP range, e.g. $F \approx 0.145$).

3. **Operational fishing mortality targets**: We recommend setting the operational target fishing mortality at the lower end of the MAP F_{MSY} range (e.g. $F \approx 0.145$; the MAP specifies a range for bass, with upper bound $F_{\text{MSY}} = 0.170$ post-benchmark) or approximately $0.6 \times F_{\text{MSY}}$, treating $F_{\text{MSY}} = 0.170$ as a hard upper bound. For clarity, 0.145 is less conservative (a higher F) than $0.6 \times F_{\text{MSY}} \approx 0.102$, and is presented as an interim MAP-consistent option pending bass-specific MSE testing. This reflects the asymmetric risk–yield trade-off identified by Winker et al. [3] and provides substantial risk reduction with minimal yield loss.

4. **Harvest control rule logic**:

   - If $B \geq B_{\text{target}}$ and T_{rebuild} is within the agreed horizon, set $F = F_{\text{target}}$ (e.g. the recommended operational target $F \approx 0.145$), ensuring that $F \leq F_{\text{MSY}}$ at all times.
   - If $B_{\text{rebuild}} < B < B_{\text{target}}$, maintain $F = F_{\text{target}}$ but monitor T_{rebuild} closely. If T_{rebuild} exceeds the agreed horizon, reduce F to F_{rebuild} until rebuilding is back on track.
   - If $B \leq B_{\text{rebuild}}$, reduce F to F_{rebuild} (or lower if necessary) until $B > B_{\text{rebuild}}$ and T_{rebuild} is demonstrably within the agreed horizon.
   - At all biomass levels, ensure that structural indicators (e.g. ABI_{MSY}, proportion of large fish) are consistent with maintaining reproductive potential and stakeholder objectives.

5. **Sector-specific implementation**: Within the total removals constraint set by the HCR, allocate removals between commercial and recreational sectors using transparent criteria. For implementation clarity, commercial dead discards should be counted against the commercial sector allocation (thereby reducing allowable commercial landings), rather than being removed from the total-removals pot before sector allocation. Consider formal sector shares (e.g. 50% commercial, 50% recreational) or sector-specific management tools (e.g. commercial quotas combined with recreational bag/slot limits) that reflect current approximate removals and stakeholder priorities. If quota instruments are used, design safeguards should prevent concentration of access rights, protect low-impact inshore/small-scale participation, and retain explicit gear-specific controls so management outcomes are not driven solely by quota ownership. Within the commercial sector, recognise the diversity of interests (targeted hooks & lines fishers, bycatch trawlers, different gear types) and ensure that all commercial sub-sectors benefit from management that maintains a large, resilient stock with a high proportion of older, larger, more fecund fish through improved catch rates, better prices (for large fish), and sustainable livelihoods.

Management Measures: The harvest control rule could be supported by a package of complementary management measures:

- **Large-fish protection**: Implement slot limits or minimum size limits that protect large, highly fecund bass, drawing on the Atlantic striped bass and Western Baltic cod examples. This supports both reproductive potential and recreational fisher satisfaction.

Framework schematic (placeholder): current ICES MSY advice rule vs proposed bass-specific framework (F as ceiling, rebuilding-time reference points, LFS, allocation).

Figure 1: Current vs proposed framework (schematic placeholder).

- **Enhanced monitoring**: Strengthen recreational and commercial catch and effort monitoring e.g. through digital reporting tools (smartphone apps) combined with survey-based validation, essential for accurate stock assessment and for evaluating sector-specific performance.
- **Spatial measures**: Consider catch-and-release zones or seasonal closures in key spawning areas, integrated with Marine Protected Area objectives where appropriate. This provides direct spawning protection and aligns with ecosystem objectives.
- **Technical measures**: Continue to refine gear restrictions, bycatch reduction devices, and discard survival improvements to minimise unwanted mortality and support rebuilding.

Performance Metrics: Candidate alternative approaches should be evaluated against a comprehensive set of performance metrics that reflect the multi-objective nature of Bass FMP goals. Metrics cover four categories:

- **Biological metrics**: probability of breaching B_{lim}, probability of achieving rebuilding targets, average SSB, age-based indicators (ABI_{MSY}), and spatial indicators
- **Economic metrics**: Gross Value Added (GVA) for commercial and recreational sectors, CPUE/LPUE, profitability indicators, and recreational trip values
- **Social–cultural metrics**: distribution of benefits between sectors, commercial fleet viability, recreational fisher satisfaction, and coastal community benefits
- **Ecological metrics**: bycatch rates, habitat impacts, and ecosystem indicators

These metrics enable transparent comparison of trade-offs between different objectives (e.g. yield vs. risk, commercial vs. recreational benefits, biological vs. economic outcomes). Potential metrics for each category are presented in Tables 2, 3, 4, and 5. Detailed tables mapping management objectives to specific metrics, and full descriptions of all performance metrics, are provided in Appendix 4.6.8 (Tables 6 and 7).

Table 2: Biological performance metrics

Metric	Target
Probability of $B < B_{\text{lim}}$	$< 5\%$
Probability of achieving B_{target} within T_{rebuild}	$> 80\%$
Average SSB relative to B_{MSY} and B_{target}	–
Age-based indicators (e.g. ABI_{MSY}, proportion of fish above characteristic size)	–
Spatial indicators (e.g. centre-of-gravity, proportion of biomass inside historical core areas)	–
Long-term average yield (to ensure that precaution does not come at excessive yield cost)	–

Table 3: Economic performance metrics

Metric	Notes
Gross Value Added (GVA) for commercial and recreational sectors separately	Sector-specific
Commercial CPUE/LPUE and profitability indicators	Commercial sector
Recreational trip values and participation rates	Recreational sector
Total economic value across sectors (for MEY/MSB evaluation)	Cross-sectoral

Table 4: Social–cultural performance metrics

Metric	Scope
Distribution of benefits between commercial and recreational sectors, and within commercial sector (targeted vs bycatch, different gear types, UK vs EU)	Cross-sectoral
Commercial fleet viability across different sub-sectors (small-scale targeted hooks & lines, bycatch trawlers, gillnet/trammel, other gear types)	Commercial sub-sectors
Recreational fisher satisfaction (e.g. catch rates, trophy fish availability)	Recreational sector
Coastal community benefits across all stakeholder groups in the UK	All stakeholders

Table 5: Ecological performance metrics

Metric	Notes
Bycatch of non-target species	Ecosystem impact
Habitat impacts	Ecosystem impact
Ecosystem indicators (e.g. trophic level, biodiversity)	Ecosystem health
Climate resilience indicators	Long-term sustainability

4.3 Management Strategy Evaluation

Candidate alternative harvest approaches should be tested and refined using MSE before a final strategy is agreed. This section outlines the key components of an MSE framework for bass. The framework is designed to support adaptive management, with iterative refinement based on MSE results, monitoring data, stakeholder feedback, and emerging evidence, ensuring that the approach evolves and improves over time.

Within ICES, MSE is used to choose and tune harvest control rules (HCRs) that are robust to uncertainty. The aim is to identify management strategies (combination of data, assessment, and HCR) that perform well across a range of plausible scenarios, not to determine which Operating Model most accurately represents reality. This shift focus from selecting a single "best" assessment to selecting a robust management strategy.

The proposed bass MSE framework is designed to be consistent with the emerging ICES Guidelines for the Implementation of MSE and the new "Management Strategy Evaluations of ICES advice rules" section in the Advice on fishing opportunities guidelines. It treats the sea bass management strategy as the combination of data, assessment, and an HCR, uses Operating Models conditioned on evidence from the benchmark assessment and ecological theory (with functional forms chosen to be consistent with evidence) and reference/robustness sets to represent uncertainty, and tunes HCR control parameters to meet the ICES precautionary criterion $P(SSB < B_{\mathrm{lim}}) < 5\%$ while remaining compatible with the MSY approach. Objectives and performance statistics follow the ICES template, and the implementation roadmap is aligned with benchmark timing and the documentation, validation, and reproducibility standards set out in the draft ICES MSE guidelines.

4.3.1 Operating Model

The Operating Model represents the "true" stock dynamics and will be based on the existing Stock Synthesis 3 (SS3) assessment for sea bass [57], using the 2025 benchmark results as the starting point. The Operating Model represents the full age-structured population dynamics, including both commercial and recreational fisheries with sector-specific selectivity patterns, and incorporates process error (recruitment variability, environmental stochasticity) and implementation error (discard mortality, compliance, effort creep).

An ensemble of Operating Models will be used to represent key uncertainties, including alternative natural mortality (M) and stock–recruitment steepness (h) combinations (based on likelihood profiles from the benchmark), alternative historical recreational removals series, alternative assumptions about stock structure and connectivity with the Bay of Biscay stock, and alternative discard mortality and post-release mortality rates. The ensemble will be structured as reference and robustness sets as required by ICES guidelines.

Operating Model conditioning involves choosing functional forms and parameterisations consistent with evidence from the benchmark assessment and ecological theory, including stock–recruitment relationships, process error structure, parameter uncertainty, and fleet selectivity patterns. Note that MSY reference points depend on fleet selectivity and sector allocation, not just biological parameters. Detailed specifications for the proposed Operating Models (Table 8), conditioning procedures (Appendix L), and fleet structures

(Table 9) are provided in Appendix G.

4.3.2 Observation Model

The Observation Model simulates the data collection and stock assessment process that connects the "true" stock dynamics (represented in the Operating Model) to the management advice. It generates simulated observations from the Operating Model and then applies the assessment method (e.g. SS3) to estimate stock status, which is then used by the harvest control rule to generate management advice.

The Observation Model simulates commercial landings and discards data, recreational catch and effort estimates, survey indices, and age/length composition data, each with appropriate error structures reflecting historical variability and current monitoring limitations. It also represents stock assessment uncertainty, including retrospective patterns, convergence issues, and uncertainty in estimated quantities (SSB, F, recruitment).

The Observation Model must be calibrated to match the performance of the current SS3 assessment, including the ability to track true stock status, the magnitude of assessment uncertainty, historical patterns of assessment bias, and the correlation structure between estimated SSB and F that affects HCR decision-making.

For computational efficiency, shortcut MSE approaches using calibrated emulators can be used for initial screening and parameter tuning, but full MSE with the complete assessment model is required for final advice provision to ensure emergent behaviours are properly captured. Detailed data types, error structures, calibration procedures, and validation methods are provided in Appendix K. Validation and calibration procedures for the overall MSE framework are further detailed in Appendix M.

4.3.3 Management Procedures

A Management Procedure (MP) is the combination of data, assessment method (or empirical indicators), and harvest control rule (HCR) that generates management advice. In the MSE framework, multiple candidate Management Procedures are tested against the ensemble of Operating Models to identify strategies that are robust to uncertainty, acceptable to stakeholders, and aligned with Bass FMP objectives.

4.3.4 Components of a Management Procedure

Each Management Procedure consists of three key components:

- **Data**: The data inputs used by the procedure (e.g. commercial landings, recreational catch estimates, survey indices, age/length composition). These are generated by the Observation Model from the Operating Model.
- **Assessment method or empirical indicators**: The method used to estimate stock status from the data. This can be:
  - A full stock assessment model (e.g. SS3) that estimates SSB, F, and recruitment

- An empirical indicator-based approach that uses direct observations (e.g. survey indices, CPUE, mean length) without a full assessment

- **Harvest control rule (HCR)**: The rule that links estimated stock status to management advice (e.g. target fishing mortality, catch limits, effort controls). The HCR specifies how management actions change in response to changes in estimated stock status.

4.3.5 Why Test Multiple Procedures?

Multiple Procedures: The MSE framework allows testing of alternative candidate management procedures. This:

- **Provides benchmarks**: Including the current ICES MSY Advice Rule allows direct comparison of proposed alternatives against the status quo
- **Explores alternatives**: Testing variants (e.g. with/without sector allocation, different F targets) reveals which design elements matter most for performance
- **Supports decision-making**: Stakeholders can see how different procedures perform across multiple objectives, facilitating evidence-based selection
- **Identifies robust options**: Procedures that perform well across the entire ensemble of Operating Models are more robust to uncertainty

The goal is not to find a single "optimal" procedure, but to identify strategies that are robust, acceptable to stakeholders, and aligned with Bass FMP objectives.

4.3.6 ICES Guidelines and Approval

Under ICES guidelines for Category 1 stocks, MSE can be used to evaluate and select management strategies that are robust to uncertainty. For advice provision, the MSE framework and selected management strategy must be peer-reviewed within a benchmark process and subsequently approved by both the Bureau (BOG) and Advisory Committee (ACOM). The candidate procedures proposed here are designed to be evaluated through this process, with the understanding that any final strategy used for ICES advice would need to meet ICES precautionary and MSY-consistent criteria (i.e. achieving $P(SSB < B_{\text{lim}}) < 5\%$ and consistency with the MSY approach), while also addressing the broader objectives of the Bass FMP.

4.3.7 Candidate Management Procedures

The MSE should test multiple candidate management procedures against the ensemble of Operating Models. Each procedure combines the same data sources and assessment method (SS3 or empirical indicators) with a different harvest control rule:

1. **Current ICES MSY Advice Rule**: The existing generic MSY advice rule as a baseline for comparison.

2. **Lower F target**: A simple rule using the recommended operational target at the lower end of the MAP range (e.g. $F \approx 0.145$), with the existing ICES biomass thresholds.

3. **Rebuilding-time-based rule**: The proposed alternative HCR using B_{rebuild}, T_{rebuild}, and the recommended operational target at the lower end of the MAP range (e.g. $F \approx 0.145$) as F_{target}.

4. **Large Fish Strategy (LFS)**: A rule designed to maintain *large individual fish* and robust age/size structure through lower F targets (well below F_{MSY}) and management measures that protect large fish (e.g. slot limits, maximum size limits). **This strategy focuses on demographic structure indicators (e.g. ABI_{MSY}, proportion of large fish) rather than total biomass.** The goal is to have many large individual fish in the population, not necessarily high total biomass. While maintaining large fish may result in higher total biomass as a consequence, the primary objective is size/age structure (lots of big fish), not total biomass per se. A stock with many large individual fish meets LFS objectives even if total biomass is moderate.

5. **Sector-allocated rules**: Variants of the above rules with explicit sector allocation (e.g. 50% commercial, 50% recreational) and sector-specific management tools.

6. **MEY-informed rules**: Rules that incorporate economic data (where available) to approximate MEY-type objectives, recognising data limitations.

4.3.8 Performance Evaluation

Each management procedure should be evaluated against the full suite of performance metrics outlined in Tables 6 and 7, using the ensemble of Operating Models to quantify uncertainty and risk. The evaluation should support adaptive learning, with results informing iterative refinement of both the MSE framework and candidate management procedures as new data become available and understanding improves. The evaluation should:

Decision Criteria: The final decision on a preferred management strategy should be made by the relevant management authority (e.g. Defra, Welsh Government, in consultation with ICES), informed by MSE results and stakeholder consensus, and aligned with Bass FMP goals and Fisheries Act 2020 objectives.

Decision framework: The MSE framework will generate a large number of performance metrics across biological, economic, social–cultural, and ecological dimensions. To translate these results into a decision on the preferred management strategy, a structured decision-making process is needed:

- **Performance thresholds**: Define minimum acceptable performance levels (e.g. $P(B < B_{\text{lim}}) < 5\%$ is a hard constraint; $P(B \geq B_{\text{target}}) > 80\%$ is a target). Management procedures that fail to meet hard constraints should be excluded from further consideration.
- **Metric weighting**: Through stakeholder engagement, assign relative weights to different metric categories (e.g. biological safety vs. economic benefits vs. social equity). This can be done formally through multi-criteria decision analysis (MCDA) or more qualitatively through structured discussion.
- **Trade-off analysis**: Present clear visualisations of trade-offs between objectives (e.g. yield vs. risk, commercial vs. recreational benefits). Use tools such as Kobe plots, radar charts, or trade-off curves to help stakeholders understand the implications of different choices.
- **Robustness testing**: Identify management procedures that perform well across multiple Operating Models and scenarios, rather than optimising for a single "best" model. Procedures that are robust to uncertainty should be preferred.
- **Stakeholder consensus building**: Use structured workshops to review MSE results, discuss trade-offs, and build consensus on preferred strategies. The decision-making process should be transparent, with clear documentation of how stakeholder input influenced the final choice.

To do this the following steps can be followed:

- Run long-term projections (e.g. 50–100 years) to assess both short-term rebuilding dynamics and long-term equilibrium performance.
- Quantify the probability distributions of key metrics under each procedure, not just point estimates.
- Identify trade-offs between objectives (e.g. yield vs. risk, commercial vs. recreational benefits, biological vs. economic outcomes).
- Test robustness to key uncertainties (e.g. natural mortality, stock–recruitment, recreational removals).
- Evaluate performance under different scenarios (e.g. climate-driven productivity changes, changes in recreational participation).

4.4 Communication of Results

To facilitate interpretation and communication of MSE results, performance statistics could be summarised using a traffic-light framework. This approach provides an intuitive visual summary of stock and ecosystem status across scenarios and time periods, supporting transparent evaluation of trade-offs and risks for both single-species and ecosystem objectives.

For each performance metric, simulated outcomes from the Operating Model ensemble are used to calculate the empirical probability of achieving targets or avoiding limits. These probabilities are then categorised into three risk levels:

- **Green** (high probability of success): Indicates that management objectives are being achieved with high probability (e.g. probability ≥ 0.66 for metrics where higher values are preferred, or probability ≤ 0.33 for metrics where lower values are preferred).
- **Amber** (intermediate): Indicates caution is warranted, with intermediate probability of achieving objectives (e.g. probability between 0.33 and 0.66, depending on the metric).
- **Red** (low probability of success): Indicates that action is urgently needed, with low probability of achieving objectives (e.g. probability < 0.33 for metrics where higher values are preferred, or probability > 0.66 for metrics where lower values are preferred).

Risk levels should be based on management risk tolerance and stakeholder input. For example, spawning stock biomass probabilities below 0.5 might be assigned red, between 0.5 and 0.66 amber, and above 0.66 green. Fishing mortality, where lower values are preferred, would use complementary breakpoints. This probabilistic, traffic-light approach enables intuitive assessment of management performance and ecosystem outcomes, supporting transparent communication of complex MSE results to stakeholders and decision-makers.

4.4.1 Communication of Uncertainty

Uncertainty is a key feature of the decision-making process, and requires stakeholders to understand the risks and trade-offs associated with different management choices.

Uncertainty communication: MSE results reflect a variety of uncertainties (e.g. recruitment variability) and structural uncertainty (e.g. model assumptions). Effective communication of this uncertainty is essential for informed decision-making:

- **Probability distributions**: Present full probability distributions of key metrics (e.g. median, 5th and 95th percentiles) rather than just point estimates, to show the range of plausible outcomes.
- **Scenario analysis**: Clearly distinguish between results that are robust across Operating Models (high confidence) versus those that are sensitive to model assumptions (low confidence). Highlight which uncertainties matter most for decision-making.
- **Time horizons**: Present results for both short-term (5–10 years) and long-term (20–50 years) horizons, recognising that short-term projections are more certain but long-term outcomes are also important for sustainability.
- **Ambiguous results**: When MSE results are ambiguous (e.g. multiple procedures perform similarly, or results are sensitive to assumptions), clearly communicate this ambiguity and recommend additional analysis or data collection to reduce uncertainty.
- **Adaptive learning**: Frame MSE as an iterative process where initial results inform data collection priorities, and the framework is updated as new data become available. This helps manage expectations about uncertainty reduction over time.

4.5 Stakeholder Engagement

The MSE process should include structured stakeholder engagement to:

- Refine performance metrics and weightings to reflect stakeholder priorities.
- Review and comment on candidate management procedures before final evaluation.
- Interpret MSE results and trade-offs in the context of Bass FMP goals and stakeholder values.
- Build consensus on preferred harvest strategies through transparent, quantitative comparison of alternatives.

4.5.1 International Coordination

Sea bass is a shared stock exploited by both UK and EU fleets under the UK–EU Trade and Cooperation Agreement (TCA). Effective harvest strategies therefore depend not only on the design of the UK management procedure, but also on the behaviour of EU partners and the extent to which both sides implement compatible rules.

The MSE framework can be used to explore illustrative coordination scenarios (full coordination, partial coordination, status quo external fishing, non-cooperation sensitivity), providing evidence to support ICES advice and TCA-related negotiations. These scenarios can inform risk-equivalent reference points, check consistency with rebuilding and LFS objectives, and provide a structured basis for international dialogue. Detailed scenario descriptions and their use in negotiations are provided in Appendix E.

4.5.2 ICES Approval of MSE-based Advice

Under ICES guidelines (ACOM March 2026, Doc 21 "Where to next with MSEs?"), MSE can be used to provide advice for all stock categories, provided that the MSE framework and selected management strategy are peer-reviewed within a benchmark process and subsequently approved by both the Bureau (BOG) and Advisory Committee (ACOM).

4.5.3 Data Requirements

4.5.4 Resource Requirements

4.6 Roadmap

The transition from the current management approach to an alternative management approach should be phased to allow for MSE development, stakeholder consultation, consensus-building on a final strategy, and institutional adaptation. This section outlines a proposed implementation roadmap. Central to this roadmap is the principle of adaptive management, with regular implementation reviews and protocols for responding to exceptional circumstances, ensuring that the strategy evolves based on performance and emerging evidence. Time-bins below link to the Recommendations and to technical detail in the Appendices (E: Operating Models; I: Observation Model; J: OM Conditioning; F: Data/Resources; G: Implementation Procedures; D: ICES Alignment; C: International coordination).

4.6.1 Implementation Reviews

The "adapt and learn" principle requires formal processes for monitoring strategy performance and responding to new information. This includes regular performance reviews (annual or biennial), automatic review triggers based on key indicators (e.g. SSB falling below B_{rebuild}, structural indicators deteriorating, major assessment revisions), exceptional circumstances protocols for responding when observations differ significantly from MSE forecasts, revision processes linked to ICES benchmark timing, and transparent documentation of all reviews and responses. This review framework ensures that the management strategy remains robust, responsive, and evidence-based, while maintaining stability and predictability for stakeholders. Detailed procedures for implementation reviews, exceptional circumstances protocols, and revision processes are provided in Appendix I.

4.6.2 Challenges

Several challenges may arise during implementation: governance and institutional barriers (ICES processes may be slow to adapt), data limitations (recreational catch and economic data are currently limited), stakeholder resistance (some may resist change from current MSY approach), international coordination (EU partners may not adopt alternative approaches), and resource constraints (MSE development requires significant resources). These challenges are not insurmountable but require proactive management and stakeholder engagement. Detailed mitigation strategies for each challenge are provided in Appendix I.

4.6.3 Short-term actions (0–12 months)

- **Initiate MSE development**: MSE development should start immediately as it will help formalise the Bass FMP goals as quantifiable objectives and show how to evaluate the trade-offs between them. This requires conditioning an Operating Model and building the MSE framework, based on the most recent ICES assessment. A 5-year development period for the MSE is realistic, and some benefits can be realised earlier with shortcut and empirical management procedures. The MSE should be explicitly linked to ICES benchmark timing and Terms of Reference (ToRs), ensuring that MSE development is scheduled and resourced as part of the formal ICES benchmark process for bass.
- **Lower F target**: Evaluate the lower end of the MAP range (e.g. a fraction of F_{MSY}) as a scenario within the MSE, using pre-agreed objectives and time horizons (short-term rebuilding trajectories, medium-term recovery, and long-term risk–yield trade-offs). This is intended to generate the evidence managers would need before considering any adjustment to current ICES advice. The rationale is that, given the flat-topped yield curve reported by Winker et al. [3], reducing F (e.g. to ∼60% of EQSIM F_{MSY}) could substantially reduce risk with limited loss in long-term yield, but this should be quantified explicitly for bass using MSE. *Phase-1 MSE will include hindcast/forward scenarios directly comparing continued use of* $F = 0.170$ *versus* $F = 0.145$ *using the operating-model ensemble and the proposed performance metrics, so the risk/yield and rebuilding trade-offs are explicit.*
- **Enhance recreational and commercial monitoring**: Evaluate the benefits of digital catch reporting for recreational bass fishing, integrated with existing survey methods (MRP/CatchWise). Acknowledge existing MRP/CatchWise validation while explaining remaining uncertainties and why they matter for MSE and allocation. Enhanced monitoring is needed to support MSE development, sector allocation, and risk analysis, not to reopen basic questions about the existence of recreational removals, and should not delay MSE development. For commercial fisheries, address RBS under-reporting and resolve issues with Under-10 Catch App/iVMS rollout gaps; improved commercial data would enhance Operating Model conditioning and risk analysis. The MSE framework can support cost–benefit analysis of enhanced monitoring by quantifying how improved data quality reduces assessment uncertainty, enables more precise management decisions, and improves performance against pre-agreed objectives (e.g. rebuilding timelines, sector allocation, risk reduction), helping justify monitoring investments. (See Appendices K, H.)

- **Define allocation accounting rules**: Agree and document the allocation accounting protocol so commercial dead discards are debited to the commercial allocation before setting allowable commercial landings, ensuring transparent implementation and avoiding ambiguity in sector shares.

- **Stakeholder consultation**: Conduct structured stakeholder workshops to elicit objectives and refine performance metrics, review candidate management procedures, and build consensus on objectives. Establish processes for ongoing stakeholder engagement and feedback.

- **Establish iterative learning**: Set up mechanisms for regular review, data collection, and framework refinement, ensuring that the approach can adapt based on MSE results, monitoring data, and stakeholder feedback.

Roadmap timeline (placeholder): 0–12 months; 1–3 years; 3–5+ years, with key milestones.

Figure 2: Roadmap timeline (placeholder).

4.6.4 Medium-term development (1–3(–5) years)

- **Complete MSE framework**: Finalise the Operating Models, observation model, and full suite of candidate management procedures. Conduct comprehensive MSE evaluation, with results informing iterative refinement of the framework. This should be completed within the ICES benchmark process, with work scheduled according to benchmark ToRs and timelines, ensuring peer review and approval by BOG and ACOM. (See Appendices G, L, K, F.)

- **Agree management objectives**: Conduct structured stakeholder engagement to refine performance metrics and build consensus on objectives that align with Bass FMP goals and Fisheries Act 2020.

- **Calibrate rebuilding reference points**: Use the MSE framework to calibrate B_{rebuild}, T_{rebuild}, and B_{target} for bass, informed by stakeholder-agreed rebuilding timeframes and biomass objectives. Review and refine these calibrations as new data become available. (See Appendices J, M.)

- **Design sector allocation**: If supported by stakeholders and MSE results, design a formal sector allocation framework with transparent criteria and implementation mechanisms. Include provisions for periodic review and adjustment based on performance and stakeholder feedback.

- **Pilot management measures**: Test large-fish protection (slot limits), catch-and-release zones, and enhanced technical measures in selected areas, with monitoring to evaluate effectiveness. Use results to refine measures before wider implementation.

- **Institutional adaptation**: Work with ICES, Defra, Welsh Government, and EU partners to adapt governance structures to support the alternative strategy, recognising the shared-stock nature of bass. Clearly distinguish UK vs EU vs England/Wales issues. State the pathway for getting an MSE-based strategy adopted through ICES (benchmark, BOG/ACOM approval) while keeping open the option of UK-specific operationalisation. Establish processes for regular review and adaptation of governance arrangements. (See Appendices F, E, I.)

4.6.5 Long-term refinement (3–5+ years)

- **Implement selected strategy**: Implement the final harvest control rule and supporting measures, based on MSE results and stakeholder consensus, with UK–EU coordination. Monitor performance and refine measures based on outcomes. (See Appendices I, M.)
- **Embed MEY/MSB frameworks**: As economic and social data improve, develop more sophisticated Maximum Economic Yield (MEY)- and Maximum Societal Benefits (MSB)-type objectives and integrate them into the evaluation of alternative harvest approaches. Continuously refine these frameworks as data quality improves. For mixed commercial-recreational bass, MEY is aspirational/long-term and currently constrained by economic data; we are using "MEY-type thinking" as a lens rather than proposing an immediate MEY control rule.
- **Routine reviews**: Establish regular review cycles (e.g. every 3–5 years) to update the MSE framework with new data, refine management procedures based on performance, and adapt to changing conditions (e.g. climate, markets, stakeholder priorities). Frame uncertainty and learning as integral to the decision-making process, with the framework evolving based on evidence, stakeholder feedback, and emerging knowledge.
- **Knowledge transfer and learning**: Share lessons learned with other mixed commercial–recreational fisheries and contribute to international best practice. Document what works, what doesn't, and why, to inform future refinements and support learning across fisheries.

This report has synthesised evidence from Section 1 (critical review of the ICES MSY Approach), Section 3 (international case studies of mixed commercial–recreational fisheries), and stakeholder feedback to propose a framework for evaluating alternative management approaches for sea bass. The key conclusions are:

4.6.6 Key findings

1. The ICES MSY Approach has been applied across many European fisheries. For bass, evidence should be judged against the full objective set, not MSY outputs alone. The ICES framework explicitly allows for review and adaptation, moving from generic approaches to frameworks that are better tailored to the specific characteristics of a resource. For bass, as a mixed commercial–recreational fishery with multiple objectives, case-specific considerations include: EQSIM-based F_{MSY} estimates may benefit from additional precautionary testing in closed-loop MSE settings (particularly given high uncertainty in recreational removals), the framework's sensitivity to model structure and technical assumptions can be addressed through MSE

testing across an ensemble of Operating Models, and case-specific harvest rules can better integrate the broader social, economic and ecosystem objectives set out in the Bass FMP and Fisheries Act 2020.

2. International case studies demonstrate that mixed commercial–recreational fisheries can be managed effectively using diverse approaches, but no single foreign model can be imported wholesale. Key design elements include formal sector allocation, large-fish protection, rebuilding-time-based reference points, and multi-objective evaluation frameworks.

3. Stakeholder feedback emphasises that bass management must move beyond MSY maximisation to explicitly address social, economic, cultural and ecological objectives. This includes recognising the diversity of stakeholders within both commercial (targeted hooks & lines, bycatch trawlers, different gear types) and recreational sectors, all of whom will benefit from management that maintains a large, resilient stock and a high proportion of large individual fish in the UK, with recreational fishing recognised as a key stakeholder and objective in its own right.

4. Simulation-tested alternatives exist that are directly applicable to bass: rebuilding-time-based reference points, more precautionary F targets, Large Fish Strategy (LFS), and MSE-based evaluation frameworks that can test multiple objectives simultaneously.

5. The candidate alternative management approaches combine these elements into coherent frameworks that treat F_{MSY} as an upper bound, use explicit rebuilding objectives, evaluate performance against multiple criteria, and integrate sector-specific considerations. Final strategy selection will be informed by MSE results and stakeholder consensus.

6. Current sub-F_{MSY} exploitation potentially means the stock can support more ambitious objectives beyond simple MSY maximisation, including large-stock strategies, improved age/size structure, and enhanced social and economic benefits. The proposed framework aims to prevent a reversion to "yield-maximising" MSY advice that would erode these gains and fail to deliver the multiple objectives set out in the Bass FMP and Fisheries Act 2020.

4.6.7 Recommendations

Based on this analysis, we recommend:

1. **Bass needs case-specific harvest rules**: Adopt the lower end of the MAP range ($F \approx 0.145$) as an *interim* operational target, providing immediate risk reduction with minimal governance change while MSE is developed. Note that 0.145 is (i) the legal lower bound of the agreed MAP F_{MSY} range (0.145–0.170, $\leq$ 5% long–term yield loss by construction) and (ii) higher than $0.6 \times F_{\text{MSY}}$ (≈ 0.102), a level that generic EQSIM/MSE results indicate is strongly risk–reducing with little yield loss. The bass–specific justification will be stress–tested in closed–loop MSE; if alternatives (e.g. other fractions of F_{MSY}) meet objectives better, the interim choice would be revisited.

2. **Start development of a bass-specific MSE**: MSE development should start immediately and is a prerequisite for delivering Bass FMP goals, not something to postpone 5–10 years. Build a comprehensive MSE framework for bass that uses ensemble Operating Models to represent uncertainty and tests candidate harvest strategies against multiple biological, economic, social and ecological objectives. A 5-year development period is realistic, and some benefits can be realised earlier with shortcut and empirical management procedures.

3. **Improved recreational and commercial monitoring**: Strengthen recreational catch and effort monitoring (acknowledging existing MRP/CatchWise validation while addressing remaining uncertainties), commercial monitoring (addressing RBS under-reporting and U10 Catch App/iVMS rollout gaps), economic data collection, and social–cultural indicators. Enhanced monitoring is needed to support MSE development, sector allocation, and risk analysis, not to reopen basic questions about the existence of recreational removals, and should not delay MSE development.

4. **Stakeholder-led multi-objective framework**: Conduct structured stakeholder engagement to refine performance metrics, review candidate management procedures, and build consensus on a preferred harvest approach through transparent, quantitative comparison of alternatives. The framework should explicitly address social, economic, cultural and ecological objectives, recognising recreational fishing as a key stakeholder and objective in its own right.

5. **Institutional adaptation**: Work with ICES, Defra, Welsh Government, and EU partners to adapt governance structures to support alternative harvest strategies that better align with Bass FMP goals and Fisheries Act 2020 objectives, while recognising the constraints of shared-stock management. The ICES framework explicitly allows for review and adaptation, moving from generic approaches to frameworks that are better tailored to the specific characteristics of a resource. Clearly distinguish UK vs EU vs England/Wales issues. State the pathway for getting an MSE-based strategy adopted through ICES (benchmark, BOG/ACOM approval) while keeping open the option of UK-specific operationalisation.

6. **Phased implementation with adaptive learning**: Follow the implementation roadmap outlined in Section 4.6, allowing for iterative refinement based on MSE results, stakeholder feedback, consensus-building on a final strategy, and emerging evidence. Establish regular review cycles to update the framework, refine management procedures based on performance, and adapt to changing conditions, ensuring continuous learning and improvement.

4.6.8 Future Directions

The alternative management approaches evaluated here represent a significant shift from the current management approach, but they are grounded in robust scientific evidence, international best practice, and stakeholder priorities. Central to this approach is the principle of adaptive management and continuous learning, where the framework evolves based on MSE results, monitoring data, stakeholder feedback, and emerging evidence. Success will depend on:

- Continued scientific development, particularly in MSE methods, ensemble modelling, and multi-objective evaluation frameworks.
- Strong stakeholder engagement and co-design processes that build trust and consensus.
- Investment in data systems and monitoring to support both assessment and evaluation.
- Adaptive governance that can accommodate innovation while maintaining accountability and coordination across jurisdictions.
- Long-term commitment to iterative improvement based on performance evaluation and learning.

The three sections of this Review of Sea Bass Harvest Strategies and Alternatives have established a solid foundation for evaluating alternatives. The ICES framework explicitly allows for review and adaptation, moving from generic approaches to frameworks that are better tailored to the specific characteristics of a resource. For bass, as a mixed commercial–recreational fishery with multiple objectives, this means developing a tailored framework that addresses the full range of FMP objectives while remaining consistent with ICES principles. The next step is to develop and test candidate approaches through MSE, engage stakeholders in refining and prioritising options, build consensus on a final strategy, and begin the phased implementation that will move bass management towards a more precautionary, multi-objective, and stakeholder-aligned framework. Throughout this process, adaptive management and continuous learning will be essential, with the framework iteratively refined based on MSE results, monitoring data, stakeholder feedback, and emerging evidence, ensuring that the approach evolves and improves over time.

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Appendices

These appendices provide supporting technical material for the MSE-based alternative strategies discussed in the main report. They include (i) the mapping from management objectives to MSE performance metrics, (ii) detailed definitions of candidate strategies (e.g. the Large Fish Strategy), (iii) the components of the modelling framework (operating/observation models and conditioning), and (iv) implementation and validation procedures used to ensure candidate strategies are robust and reproducible.

Overview:

- Performance metrics: how objectives are translated into MSE scoring/decision criteria.
- Modelling: how uncertainty is represented and how candidate harvest control rules are tested.
- Implementation and validation: protocols, calibration, and verification for the full MSE framework.

Contents (in reading order):

- Performance metrics mapping and metric tables
- Large Fish Strategy (LFS) details
- International coordination scenarios
- ICES alignment and approval process
- Operating models and fleet specifications
- Data and resource requirements
- Implementation procedures
- Case-specific limitations and considerations for bass
- Observation model details
- Operating model conditioning procedures
- Validation and calibration procedures

A Management Objectives and Corresponding MSE Performance Metrics

Table 6: Mapping of management objectives to MSE performance metrics for evaluating alternative harvest strategies for northern sea bass. Each objective is evaluated against a suite of metrics across biological, economic, social–cultural, and ecological dimensions.

Management Objective	Corresponding MSE Performance Metrics
MSY (Maximum Sustainable Yield)	**Biological:** Long-term average yield, average SSB relative to B_{MSY}, $P(B < B_{\mathrm{lim}})$ **Economic:** Total catch value, GVA (commercial sector) **Note:** Traditional MSY focuses on yield maximisation; does not explicitly address rebuilding, structure, or sector distribution
MEY (Maximum Economic Yield)	**Economic:** Net present value of profits, GVA (commercial + recreational), commercial CPUE/LPUE, profitability indicators, recreational trip values **Biological:** Average SSB (typically higher than MSY), $P(B < B_{\mathrm{lim}})$ **Social–cultural:** Total economic value across sectors
LFS (Large Fish Strategy)	**Biological:** Average SSB relative to B_{target} (e.g. $1.2 \times B_{\mathrm{MSY}}$), age-based indicators (ABI_{MSY}), proportion of fish above characteristic size, spatial indicators (distribution, range, local density) **Economic:** CPUE/LPUE trends, recreational trip values **Social–cultural:** Recreational fisher satisfaction (catch rates, trophy fish availability)
MSB (Maximum Societal Benefits)	**Economic:** Total GVA (commercial + recreational), total economic value across sectors, commercial profitability, recreational trip values and participation rates **Social–cultural:** Distribution of benefits between sectors, small-scale commercial fleet viability, coastal community benefits, recreational fisher satisfaction **Biological:** Average SSB, $P(B < B_{\mathrm{lim}})$, stock structure indicators
ESY (Ecologically Sustainable Yield)	**Ecological:** Bycatch of non-target species, habitat impacts, ecosystem indicators (trophic level, biodiversity), climate resilience indicators **Biological:** Average SSB (typically higher than MSY), $P(B < B_{\mathrm{lim}})$,

Continued on next page

Table 6 continued

Management Objective	Corresponding MSE Performance Metrics
	age-based and spatial indicators
Precautionary/ Risk-based	**Biological:** $P(B < B_{\text{lim}})$ (target: $< 5\%$), P(achieving B_{target} within T_{rebuild}) (target: $> 80\%$), average SSB relative to B_{MSY} and B_{target} **Note:** Uses lower F targets (e.g. $F = 0.145$ or $0.6 \times F_{\text{MSY}}$) to reduce risk
Rebuilding objectives	**Biological:** P(achieving B_{target} within T_{rebuild}) (target: $>$ 80%), B_{rebuild} and T_{rebuild} calibration, average SSB trajectory **Note:** Explicit biomass targets and timeframes; rebuilding-time-based reference points
Sector integration/ Equity	**Social–cultural:** Distribution of benefits between commercial and recreational sectors, small-scale commercial fleet viability, recreational fisher satisfaction **Economic:** GVA by sector (commercial vs recreational), sector-specific CPUE/LPUE, sector catch allocation, total economic value across sectors **Biological:** Sector-specific removals, stock structure indicators

Notes: This table maps management objectives (MSY, MEY, LFS, MSB, ESY, precautionary/risk-based, rebuilding, sector integration) to MSE performance metrics. The MSE framework tests harvest control rules against this suite, enabling transparent comparison of trade-offs. Metrics span biological, economic, social–cultural, and ecological categories. The alternative strategy targets multiple objectives simultaneously (e.g. precautionary rebuilding with sector equity and LFS outcomes).

B MSE Performance Metrics

Table 7: Performance metrics used to evaluate candidate harvest control rules in the MSE framework for northern sea bass. Metrics are categorised into traditional fisheries objectives (Safety, Status, Yield) and additional ecosystem and multi-objective metrics (Structural, Rebuilding, Spatial, Economic, Social–cultural, Ecological).

Metric Category	Description
Safety: $P(B < B_{\text{lim}})$	Avoiding stock depletion where productivity is impaired, commonly defined by a biomass limit B_{lim} based on stock biology. Target: probability $< 5\%$.

Continued on next page

Table 7 continued

Metric Category	Description
Status: $P(B \geq B_{\text{target}})$, $P(F \leq F_{\text{MSY}})$	Achieving targets related to maintaining the stock at target biomass (B_{target}) and fishing mortality levels. For the alternative strategy, B_{target} is at least B_{MSY} and potentially higher (e.g. $1.2 \times B_{\text{MSY}}$).
Yield: $P(\text{Yield} \geq 0.80 \times \text{MSY})$	Achieving continuing catches close to Maximum Sustainable Yield (MSY), keeping catch within the Pretty Good Yield (PGY) range that produces catches on average at least 80% of MSY. Ensures that precaution does not come at excessive yield cost.
ABI_{MSY}	Age-Based Indicator comparing the current age structure of the stock with the equilibrium age structure at B_{MSY}, providing insight into demographic resilience. ABI_{MSY} would be tracked alongside SSB, with soft/hard bounds to indicate erosion of large-fish structure that should trigger review of measures.
Rebuilding Time	Time required for SSB to rebuild to B_{target} after depletion, expressed in generation time units. Measures the capacity of the stock to recover while maintaining the delivery of ecosystem services. Target: probability of achieving B_{target} within $T_{\text{rebuild}} > 80\%$.
Spatial Indicators	Metrics tracking distribution, range, and local density. Candidate metrics include centre-of-gravity (tracking the geographic centre of biomass distribution) and the proportion of biomass inside historical core areas (e.g. key spawning or nursery grounds). Provides early warning of depletion and tracks recovery trajectories.
Economic: GVA, CPUE/LPUE, profitability	Gross Value Added (GVA) for commercial and recreational sectors separately, commercial CPUE/LPUE and profitability indicators, recreational trip values and participation rates, total economic value across sectors (for MEY/MSB evaluation).
Social–cultural: Sector distribution, viability, satisfaction	Distribution of benefits between commercial and recreational sectors, small-scale commercial fleet viability, recreational fisher satisfaction (e.g. catch rates, trophy fish availability), coastal community benefits.

Ecological: Bycatch, habitat, ecosystem indicators	Bycatch of non-target species, habitat impacts, ecosystem indicators (e.g. trophic level, biodiversity), climate resilience indicators.

Notes: These metrics evaluate the ability of harvest control rules to maintain stock biomass at levels consistent with achieving management objectives, prevent stock depletion, and align with broader ecosystem and socio-economic objectives. Safety relates to avoiding stock depletion where productivity is impaired, status refers to achieving targets, and yield aims at achieving catches close to MSY while ensuring precaution does not come at excessive yield cost. The additional metrics (ABI_{MSY}, Rebuilding Time, Spatial Indicators, Economic, Social–cultural, Ecological) support the multi-objective nature of Bass FMP Goals 5 and 6, enabling evaluation of trade-offs between biological, economic, social and ecological outcomes.

C Mapping Objectives to Performance Metrics

From objectives to measurable outcomes: The multi-objective nature of bass management requires a clear mapping between high-level objectives (from Bass FMP Goals 5 and 6, Fisheries Act 2020, and stakeholder priorities) and the specific performance metrics used in MSE evaluation.

This mapping ensures that:

- **Objectives are operationalised**: High-level goals are translated into measurable metrics.
- **Trade-offs are transparent**: Conflicts (e.g. yield vs risk; commercial vs recreational benefits) are visible in comparable indicators.
- **Stakeholder priorities are reflected**: Different stakeholder concerns are explicitly represented in the evaluation framework.

Objective Categories and Metric Mapping

Biological objectives (Bass FMP Goal 6, precautionary management):

- Objective: Maintain stock above B_{lim} with high probability.
- Metrics: $P(SSB < B_{\text{lim}})$ (target: $< 5\%$), time below B_{lim}, median SSB.
- Objective: Rebuild to B_{target} within agreed timeframe.
- Metrics: $P(B \geq B_{\text{target}} \text{ within } T_{\text{rebuild}})$ (target: $> 80\%$), time to recovery.
- Objective: Maintain demographic population structure (Large Fish Strategy).
- Metrics: ABI_{MSY}, proportion of biomass above size threshold, mean age of spawners.
- Objective: Maintain spatial distribution and availability.
- Metrics: Centre-of-gravity, proportion of biomass in historical core areas, spatial CPUE indices.

Economic objectives (Bass FMP Goal 5, commercial sector):

- Objective: Maximise commercial sector value and profitability.
- Metrics: Commercial GVA, commercial CPUE/LPUE, ex-vessel prices, vessel profitability.
- Objective: Maximise total economic value (MEY/MSB).
- Metrics: Total GVA (commercial + recreational), net present value, economic efficiency.
- Objective: Support sustainable commercial livelihoods.
- Metrics: Interannual variability in catch/TAC, stability of commercial access, distribution of benefits across commercial sub-sectors.

Social–cultural objectives (Bass FMP Goal 5, recreational sector and coastal communities):

- Objective: Maximise recreational fisher satisfaction and participation.
- Metrics: Recreational trip values, catch rates (CPUE), participation rates, recreational fisher satisfaction surveys.
- Objective: Support coastal community benefits.
- Metrics: Recreational GVA, tourism-related economic activity, employment in recreational fishing businesses.
- Objective: Ensure equitable access and distribution of benefits.
- Metrics: Sector allocation shares, distribution of benefits across stakeholder groups, access indicators.

Ecological objectives (Bass FMP Goal 6, ecosystem health):

- Objective: Maintain ecosystem resilience and Good Environmental Status (GES).
- Metrics: Age/size structure indicators (ABI_{MSY}), spatial distribution metrics, bycatch rates, discard mortality.
- Objective: Support trophic interactions and ecosystem function.
- Metrics: Predator–prey indicators (where data available), habitat impact assessments.

Using the mapping in decision-making:

- Each objective should be represented by at least one primary metric (and ideally multiple complementary metrics).
- Stakeholder engagement should confirm that the metric mapping accurately reflects priorities and concerns.
- Trade-off analysis should compare procedures across the full objective set, not only biological metrics.
- Decision criteria should weight objectives according to stakeholder priorities and policy requirements (e.g. Bass FMP Goals 5 and 6).

This mapping ensures that MSE evaluates management procedures against the full range of objectives that matter to stakeholders and policy-makers.

D Large Fish Strategy (LFS) – Detailed Explanation

What is meant by a Large Fish Strategy?: A Large Fish Strategy (LFS) aims to conserve a high proportion of big, old bass in the population, recognising that these fish contribute disproportionately to reproduction, stock resilience, and the quality of recreational fishing. In practice, this means designing harvest rules and supporting measures that avoid systematically removing the largest fish and that allow old-growth age and size structure to rebuild and be maintained.

How can LFS measures be built into the harvest control rule?: The LFS can be represented in the Harvest Control Rule (HCR) by linking exploitation rates and catch limits to explicit structural indicators as well as biomass. Examples include:

- Defining a structural target, such as maintaining the proportion of biomass above a reference length (e.g. L_{LFS}) above a specified threshold, or keeping an age- or size-based indicator (e.g. an Age-Based Indicator for MSY (ABI_{MSY})-type index) above a target level.
- Adjusting the target fishing mortality when large-fish indicators deteriorate. For example, if the proportion of biomass in large fish falls below its target, the HCR can automatically reduce the target F or apply an additional reduction factor to total removals until structural indicators recover.
- Incorporating LFS status in rebuilding objectives. Rebuilding targets can be framed as "reach B_{target} *and* restore large-fish indicators to agreed levels within a specified time frame", rather than focusing on spawning biomass alone.

These structural triggers can be implemented alongside biomass-based reference points such as B_{rebuild} and B_{trigger}, so that the same HCR simultaneously protects overall biomass and the contribution of large fish.

Examples of management measures consistent with LFS: Several concrete management tools can be used to implement an LFS within and alongside the HCR:

- **Harvest slots and maximum size limits**: Regulations can specify a minimum and maximum size for retention, with the largest bass released alive. In the MSE, this is represented by selectivity-at-length that declines at large sizes, reducing fishing mortality on the biggest fish while still allowing harvest of mid-sized fish.
- **Nursery and aggregation area protection**: Seasonal or permanent closures in key nursery grounds and adult aggregation areas can be modelled as spatial reductions in fishing mortality, allowing older fish to accumulate in low-risk zones and contribute to spawning.
- **Gear and hook regulations**: Technical measures (e.g. hook size, mesh size, or gear restrictions in specific areas) can be parameterised in the Operating Model as changes in selectivity patterns that reduce catchability of large fish or vulnerable life stages.

In each case, the essential feature is that the management measure reduces effective fishing mortality on the largest individuals, which is then reflected in the simulated length and age composition under the HCR.

Evaluating LFS in Management Strategy Evaluation: Within the Management Strategy Evaluation (MSE) framework, alternative LFS designs can be tested by:

- Comparing scenarios with and without LFS measures (e.g. with and without a harvest slot, with varying strength of maximum size limits, or with different levels of spatial protection) while keeping other aspects of the HCR constant.
- Tracking structural indicators (e.g. proportion of biomass above L_{LFS}, mean length of spawners, age-based indices) alongside biomass-based metrics to assess whether large-fish components are rebuilt and maintained.
- Assessing trade-offs between LFS strength and yields or catch opportunities in different sectors, using common performance metrics.

This allows decision-makers to see how strongly LFS measures must be applied to achieve structural objectives, and what the implications are for catches and effort over time.

Benefits for the recreational sector: A well-designed LFS has particular benefits for the recreational sector:

- **More trophy fish**: Conserving large fish increases the probability that recreational fishers encounter trophy-sized bass, which is closely linked to recreational fisher satisfaction and the perceived quality of the fishery.
- **Stable, high-quality recreational fishing**: Maintaining old-growth structure tends to stabilise recruitment and size composition, reducing boom–bust dynamics and providing more consistent opportunities for memorable catches year after year.
- **Local economic value**: High-quality recreational fishing for large fish supports guiding businesses, charter operations, tackle and tourism spending in coastal communities. These benefits can be captured in MSE via simple economic or social performance metrics (e.g. indices of recreational fishing days, trip value, or satisfaction) that respond positively when the abundance of large fish increases.

By explicitly including these recreational benefits in the performance metrics, the MSE can show how LFS-oriented harvest strategies contribute to both ecological resilience and long-term social and economic objectives for coastal communities.

E International Coordination Scenarios

Why international coordination matters: Northern sea bass is a shared stock exploited by both UK and EU fleets under the UK–EU Trade and Cooperation Agreement (TCA). Effective harvest strategies therefore depend not only on the design of the UK management procedure, but also on the behaviour of EU partners and the extent to which both sides implement compatible rules. The MSE framework can be used to explore a small set of illustrative coordination and non-coordination scenarios, providing evidence to support ICES advice and TCA-related negotiations.

Illustrative scenarios to test in MSE: For communication purposes, a limited number of contrasting scenarios is preferable. Examples include:

- **Full coordination**: UK and EU both adopt the same bass Harvest Control Rule (HCR), including rebuilding targets, Large Fish Strategy elements, and sector-specific measures. Total fishing mortality and rebuilding performance are evaluated under the assumption of joint implementation.
- **Partial coordination**: UK implements the new HCR (e.g. with more precautionary F and stronger structural safeguards), while EU continues with a broadly similar rule but with higher target exploitation or delayed rebuilding. This scenario highlights the extent to which unilateral UK measures can improve stock status and domestic benefits when external fishing mortality remains higher.
- **Status quo external fishing**: UK implements the new HCR, but EU fishing mortality is held at a level consistent with current ICES MSY-based advice. This provides a baseline for understanding the incremental gains from UK action in the absence of formal changes on the EU side.
- **Non-cooperation sensitivity**: A small set of "stress-test" scenarios in which EU fishing mortality exceeds levels consistent with precautionary advice (e.g. due to implementation error or delayed response) can be used to assess the robustness of UK measures to adverse external conditions.

In each case, the same Operating Models are used, but assumptions about how total fishing mortality is split and controlled between UK and EU are varied. Performance is then compared across biological, economic, social, and structural metrics.

Linking scenario results to ICES advice: The scenario results can inform and complement ICES advice in several ways:

- They provide quantitative evidence on how different combinations of UK and EU management behaviour affect the probability of meeting biomass and rebuilding targets, as well as demographic and spatial objectives.
- They can be used to derive risk-equivalent reference points or catch options that remain precautionary under realistic coordination assumptions, supporting the development of harvest strategies that are robust to moderate deviations from ideal behaviour.
- They offer a way to check whether current or proposed ICES MSY-based advice is consistent with the rebuilding and Large Fish Strategy objectives explored in the MSE.

Use in TCA-related negotiations: Finally, these scenarios provide a structured basis for international dialogue:

- The full-coordination scenario illustrates the potential shared benefits (higher long-term yields, more stable biomass, improved recreational and community outcomes) that could be achieved if both parties adopt compatible harvest rules.
- Partial and status-quo scenarios show the consequences of asymmetric action, helping negotiators understand what the UK can achieve unilaterally and where cooperative action would deliver additional gains.
- Stress-test scenarios highlight the risks of non-cooperation, including increased probability of breaching biomass limits or failing to meet rebuilding timelines, thereby underlining the value of joint commitments.

By presenting these results in the same traffic-light and summary format used for domestic options, the MSE framework can translate complex international dynamics into clear evidence to support ICES deliberations and TCA-related decision-making.

F ICES Alignment and Approval Process

F.1 ICES Guidelines for MSE-based Advice

Under ICES guidelines (ACOM March 2026, Doc 21 "Where to next with MSEs?"), MSE can be used to provide advice for all stock categories, provided that:

- The MSE framework and selected management strategy are peer-reviewed within a benchmark process
- The approach is subsequently approved by both the Bureau (BOG) and Advisory Committee (ACOM)
- For Category 1 stocks such as northern sea bass, the management strategy (comprising data, assessment model, and harvest control rule) is robust to uncertainty

F.2 Conceptual Alignment with ICES Framework

The proposed bass MSE framework aligns conceptually with ICES guidelines across multiple dimensions:

- **Use of MSE for advice across categories**: ICES now explicitly allows advice based on MSE for all stock categories, provided it is benchmark-reviewed and approved by BOG/ACOM. This framework proposes exactly that for a Category 1 stock: use MSE at the benchmark to select and tune an HCR, rather than just a preferred assessment, and then base advice on that HCR.
- **Definition of management strategy and HCR tuning**: ICES defines a strategy as data + assessment + HCR and states that the same HCR used in MSE should be used for advice, with MSE used to tune control parameters to meet $P(SSB < B_{\text{lim}}) < 0.05$ and MSY consistency. Section 4.2.5 does this by specifying candidate HCRs (B_{rebuild}, T_{rebuild}, $F_{\text{target}} \leq F_{\text{MSY}}$, LFS triggers) and proposing to calibrate them in MSE against biological, economic, social, and ecological metrics.
- **Operating model conditioning and uncertainty**: The ICES guidelines emphasise conditioning the OM by choosing functional forms (e.g. stock–recruitment relationships such as Beverton–Holt or Ricker, avoiding biologically implausible forms like segmented regression/hockey-stick) that are consistent with evidence from the benchmark assessment and ecological theory, representing parameter uncertainty, process error structure (which affects feedback control rule performance), and fleet selectivity patterns (since MSY depends on selectivity, not just biology). For Category 1 stocks like bass, conditioning uses evidence from the benchmark assessment and ecological theory; for Category 3 stocks, conditioning would be based primarily on ecological theory. This framework's OM section mirrors this: it conditions functional forms on evidence from the bass assessment and ecological theory, explores productivity, structure and spatial uncertainty, and sets up reference/robustness OM grids for bass.
- **Precautionary risk standard**: ICES uses the 5% B_{lim} risk criterion and equivalent recovery targets, with emphasis on tail-probability precision and reporting of yield, SSB, TAC variability, etc. Section 4.2.5 adopts the same risk framing (B_{rebuild}, T_{rebuild}, $P(SSB \geq B_{\text{target}}$ within $T_{\text{rebuild}})$, lower $F_{\text{target}} \approx 0.6 \times F_{\text{MSY}}$ to reduce risk) and adds structure and sector metrics on top.

- **Objectives and performance statistics**: The guidelines call for clear objectives and performance statistics; Table 6 (MSY, MEY, LFS, MSB, ESY, precaution, rebuilding, equity → biological, economic, social–cultural, ecological metrics) is a direct instantiation of that requirement.
- **Full vs shortcut MSE, emulators, efficiency**: ICES encourages full MSE where possible, with calibrated shortcut/emulator approaches for efficiency, plus bootstrap-based stopping rules. This report explicitly proposes a full OM/MP structure and could easily incorporate emulator-based tuning and bootstrap precision control as per the guidelines.
- **Validation, documentation, and benchmark linkage**: The guidelines stress hindcasts, retrospectives, worm plots, protocol tables, TAF code release, and alignment with benchmark schedules. Appendix M and Section 4.6 already provide the validation/calibration procedures and implementation roadmap that can be explicitly tied to an ICES benchmark and documentation package.

F.3 Alignment with ICES Requirements

The candidate management procedures proposed in this document are designed to be evaluated through the ICES benchmark process. Key considerations:

- **Precautionary criterion**: All candidate procedures must achieve $P(SSB < B_{\text{lim}}) < 5\%$ to meet ICES precautionary requirements. The rebuilding-time-based and LFS procedures proposed here are designed to be more precautionary than the current ICES MSY Advice Rule.
- **MSY-consistency**: ICES guidelines require strategies to be "consistent with the MSY approach." The candidate procedures proposed here treat F_{MSY} as an upper bound and use lower target fishing mortalities, which is consistent with MSY principles while addressing broader objectives. Procedures that explicitly target objectives beyond MSY (e.g. MEY, LFS, MSB) would need to demonstrate that they remain consistent with MSY principles or would require explicit policy justification for moving beyond MSY-consistency.
- **Benchmark process**: The MSE framework should be developed and validated as part of the ICES benchmark process for bass, ensuring peer review and scientific credibility before any management strategy is used for advice.
- **Operating model structure**: ICES guidelines require operating models to include both reference and alternative sets that reflect plausible ranges of uncertainty. The ensemble operating model approach proposed here (Section 4.1) aligns with this requirement.
- **Technical requirements**: The framework proposed here follows ICES guidelines for OM conditioning (choosing functional forms consistent with evidence from the benchmark assessment and ecological theory, with the SS3 benchmark assessment providing the evidence base for bass), recruitment representation (avoiding biologically implausible forms like segmented regression), selectivity (recognising that MSY depends on fleet selection patterns), natural mortality, process error structure, and validation through hindcasting and retrospectives.

F.4 Interpretation of HCR Alignment Requirement

The ICES guidelines state that for Category 1–3 stocks, "the HCR applied during the MSE should be the same rule used by ICES to provide advice. MSE should be used to tune the HCR control parameters to ensure that the strategy meets precautionary and MSY-consistent criteria." This text can be interpreted in two ways:

- **Narrow interpretation**: Only tuning the control parameters of the existing ICES MSY Advice Rule (e.g. adjusting F_{target} or $MSY\ B_{\text{trigger}}$ values).
- **Broader interpretation**: Testing alternative HCR structures within the benchmark process, with the selected HCR becoming the formal ICES advice rule for bass.

The approach proposed here follows the broader interpretation: evaluating multiple candidate HCRs (including rebuilding-time-based rules, LFS variants, and sector-specific rules) through MSE, with the understanding that:

- Any final strategy selected for ICES advice would need to meet ICES requirements (precautionary criterion, MSY-consistency or explicit policy justification) and be formally adopted as the ICES advice rule for bass.
- The MSE evaluation would occur within the ICES benchmark process, ensuring peer review and scientific credibility.
- This approach aligns with ICES guidance that MSE can be used to "evaluate and select a management strategy that is robust to uncertainty instead of focusing on identifying a single preferred assessment model."

If ICES requires the narrow interpretation (parameter tuning only), the framework proposed here could be adapted to test variants of the existing ICES MSY Advice Rule with different parameter settings, while still addressing Bass FMP Goals 5 and 6 through the choice of parameter values and supporting management measures.

G Operating Models and Fleet Specifications

G.1 Operating Models

Table 8: Proposed ensemble of operating models for MSE testing, representing key uncertainties in natural mortality (M), stock–recruitment steepness (h), historical recreational removals, stock structure, and implementation parameters. Models are based on Stock Synthesis 3 (SS3) assessment conditioned on 2025 benchmark results.

Model ID	M	h	**Rec. Removals**	**Stock Structure**	**Discard/Release**	**Priority**	**Rationale**
OM-1 (Baseline)	Base	Base	Base	Single	Base	**High**	Baseline reference for comparison
OM-2 (High productivity)	Low	High	Base	Single	Base	**High**	Tests precaution under optimistic biological assumptions
OM-3 (Low productivity)	High	Low	Base	Single	Base	**High**	Tests robustness under pessimistic biological assumptions
OM-4 (High rec. removals)	Base	Base	+20%	Single	Base	**High**	Tests sensitivity to underestimation of historical recreational catch
OM-5 (Low rec. removals)	Base	Base	−20%	Single	Base	**High**	Tests sensitivity to overestimation of historical recreational catch
OM-6 (Meta-population)	Base	Base	Base	Meta-pop.	Base	**Medium**	Tests sensitivity to stock structure assumptions (connectivity with Bay of Biscay)
OM-7 (High discard)	Base	Base	Base	Single	High discard	**Medium**	Tests sensitivity to commercial discard mortality assumptions
OM-8 (High C&R mortality)	Base	Base	Base	Single	High C&R	**Medium**	Tests sensitivity to recreational catch-and-release mortality assumptions

Continued on next page

Table 8 (continued)

Model ID	M	h	Rec. Removals	Stock Structure	Discard/Release	Priority	Rationale
OM-9 (Optimistic)	Low	High	+20%	Meta-pop.	Base	**Low**	Extreme optimistic scenario for robustness testing
OM-10 (Pessimistic)	High	Low	+20%	Single	High both	**Low**	Extreme pessimistic scenario for robustness testing

Model specifications: All operating models are age-structured, include both commercial and recreational fisheries with sector-specific selectivity and catchability, and incorporate process error (recruitment variability) and implementation error. **Base** values refer to the 2025 benchmark assessment estimates. **Low/High** M and h values are selected from likelihood profiles from the benchmark (e.g., 5th and 95th percentiles or alternative local maxima). **Recreational removals** scenarios represent uncertainty in historical catch estimates. **Stock structure** scenarios test sensitivity to assumptions about connectivity with the Bay of Biscay stock. **Discard/Release mortality** scenarios test sensitivity to implementation assumptions. Priority ranking reflects importance for initial MSE testing: High-priority models represent core uncertainties that must be included; Medium-priority models test additional structural assumptions; Low-priority models represent extreme combinations for robustness testing.

G.2 Fleet Specifications

Table 9: Fleet specifications for the MSE operating models, representing commercial and recreational fisheries with sector-specific selectivity patterns, catchability, and effort dynamics. Fleets are based on the 2025 benchmark assessment structure.

Fleet ID	Sector	Gear Type	Selectivity Pattern	Key Characteristics
F1 (Targeted)	Commercial	Hooks & Lines (longlines, handlines)	Dome-shaped (peaks at large sizes)	Targeted bass fishery; historical authorisations; low discard mortality
F2 (Gillnets/Trammel)	Commercial	Fixed nets (gillnets, trammel nets)	Asymptotic (plateaus for large fish)	Targeted bass fishery; size-selective; moderate discard mortality
F3 (Bycatch trawl)	Commercial	Bottom trawl (otter trawl)	Asymptotic (plateaus for large fish)	Bycatch fishery; mixed-species; high discard mortality
F4 (Other commercial)	Commercial	Other passive (seines, other)	Variable (gear-dependent)	Mixed gear types; bycatch component; variable discard mortality

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Table 9 (continued)

Fleet ID	Sector	Gear Type	Selectivity Pattern	Key Characteristics
F5 (Shore recreational fishing)	Recreational	Rod & line (from shore)	Dome-shaped (targets large fish)	Shore recreational fishing; catch-and-release; low post-release mortality
F6 (Boat recreational fishing)	Recreational	Rod & line (from boat)	Dome-shaped (targets large fish)	Boat recreational fishing; catch-and-release; low post-release mortality
F7 (Charter/guided)	Recreational	Rod & line (charter boats)	Dome-shaped (targets large fish)	Charter/guided; higher effort intensity; commercial-recreational hybrid

Fleet specifications: All fleets are age-structured with fleet-specific selectivity, catchability, and effort dynamics. **Commercial fleets** (F1–F4) include both landings and discards, with discard mortality rates varying by gear type. **Recreational fleets** (F5–F7) include both retained catch (subject to bag limits) and catch-and-release, with post-release mortality rates. Selectivity patterns are estimated from age/length composition data in the assessment. **Dome-shaped selectivity** indicates vulnerability peaks then declines for largest fish (typical of hooks & lines and recreational gear targeting specific size ranges). **Asymptotic selectivity** indicates vulnerability plateaus for larger fish (typical of nets and trawls). Fleet-specific catchability and effort dynamics model sector responses to management measures (e.g., recreational effort response to bag limits, commercial effort reallocation). For UK-focused MSE, fleets can be aggregated by country (UK vs non-UK) or kept separate if spatial structure is important.

H Data and Resource Requirements

H.1 Data Requirements and Priorities

Data needs for MSE development and evaluation: The MSE framework requires various data types, with different priorities and timelines:

- **Critical for initial MSE development** (Years 1–2):
  - Commercial landings and discards data (existing, but needs continued collection)
  - Recreational catch and effort estimates (currently limited; priority for enhancement through digital reporting)
  - Survey indices (existing surveys need continued support)
  - Age and length composition data (existing, but sampling could be enhanced)
- **Important for comprehensive evaluation** (Years 2–5):
  - Economic data: Commercial vessel costs, ex-vessel prices, recreational trip values, GVA estimates
  - Social–cultural data: Angler satisfaction surveys, coastal community benefits assessments
  - Demographic structure data: Enhanced age/length sampling to track ABI_{MSY} and size structure
  - Spatial data: Distribution surveys, tagging studies to understand connectivity
- **Desirable for advanced objectives** (Years 5–10):
  - Ecosystem data: Bycatch monitoring, habitat impact assessments, trophic interactions
  - Climate data: Productivity and distribution indicators, climate resilience metrics
  - Long-term time series: For validating MSE framework and adaptive management

The MSE framework can be developed incrementally, starting with biological data and expanding to include economic and social metrics as data improve. However, recreational catch and effort monitoring is a critical priority, as current data limitations significantly constrain assessment and MSE development.

H.2 Resource Requirements

Resources needed for MSE development and implementation:

- **Expertise**: Requires fisheries scientists with expertise in stock assessment (SS3), MSE methodology, and mixed commercial–recreational fisheries. Estimated: 1–2 FTE scientists for 2–3 years for initial development, plus ongoing support for updates and refinements.
- **Computational resources**: MSE simulations are computationally intensive, requiring high-performance computing or cloud computing resources. Estimated: Moderate computational requirements (can run on standard workstations for simplified versions, but full ensemble may require cluster computing).
- **Timeframe**: Initial MSE framework development: 2–3 years. Full evaluation with stakeholder engagement: additional 1–2 years. Ongoing updates and refinements: ongoing (e.g. every 3–5 years as part of adaptive management).
- **Data collection**: Enhanced recreational monitoring and economic data collection require dedicated resources. Estimated: Additional monitoring costs of £100,000–200,000 per year for recreational catch reporting and validation surveys.
- **Stakeholder engagement**: Structured workshops and consultation processes require facilitation and coordination. Estimated: 3–5 workshops over 2–3 years, plus ongoing engagement.

The investment in MSE development is substantial but justified by the need for robust, evidence-based management that addresses multiple objectives and stakeholder priorities. The framework can be developed incrementally, with initial simplified versions providing value while more comprehensive versions are developed.

I Implementation Procedures

I.1 Implementation Reviews and Exceptional Circumstances

Adaptive management through regular reviews: The "adapt and learn" principle requires formal processes for monitoring strategy performance and responding to new information. Key components:

- **Regular performance reviews**: Conduct annual or biennial reviews comparing observed outcomes (biomass trends, catch levels, economic indicators, structural metrics) with MSE projections. Identify discrepancies, investigate causes (e.g. assessment revisions, environmental changes, implementation deviations), and document lessons learned.
- **Review triggers**: Establish automatic review triggers based on key indicators:
  - SSB falls below B_{rebuild} or approaches B_{lim}
  - Structural indicators (ABI_{MSY}, proportion of large fish) deteriorate below agreed thresholds
  - Observed removals consistently exceed or fall below advice by significant margins
  - Major retrospective revisions in stock assessment
  - Evidence of regime shifts or environmental changes affecting productivity
- **Exceptional circumstances protocol**: Define a clear process for responding when observations differ significantly from MSE forecasts or when external shocks occur:
  - **Assessment**: Evaluate whether discrepancies are due to:
    * Normal variability within expected ranges
    * Assessment model issues or data quality problems
    * Changes in stock dynamics not captured in the operating model
    * Implementation errors or non-compliance
    * External shocks (disease, extreme environmental events, market disruptions)
  - **Response options**: Depending on the cause and severity:
    * Continue current strategy with enhanced monitoring
    * Adjust management measures within the existing HCR framework
    * Re-calibrate reference points (B_{rebuild}, T_{rebuild}, B_{target}) if assessment changes are substantial
    * Update the operating model and re-run MSE if fundamental assumptions change
    * Trigger an ICES benchmark review if major assessment revisions are needed
  - **Decision-making**: Establish clear governance for exceptional circumstances decisions, involving scientific advisors, managers, and stakeholders, with transparent documentation of rationale.
- **Revision process**: Link reviews to ICES benchmark timing (typically every 3–5 years) or conduct ad-hoc reviews when exceptional circumstances are identified. Revisions may involve:

- Updating the operating model ensemble with new data, improved understanding of stock dynamics, or revised assumptions about recruitment, natural mortality, or selectivity
  - Re-calibrating rebuilding reference points based on updated assessment results
  - Adjusting management procedure parameters or HCR structure if performance is consistently poor
  - Re-running MSE evaluation if operating model changes are substantial
  - Updating performance metrics or decision criteria based on stakeholder feedback or policy changes

- **Documentation and transparency**: All reviews, revisions, and exceptional circumstances responses should be:
  - Documented with clear rationale, evidence, and stakeholder input
  - Communicated transparently to all stakeholders
  - Integrated into the MSE framework documentation and code repository
  - Used to inform future MSE development and best practice

This review framework ensures that the management strategy remains robust, responsive, and evidence-based, while maintaining stability and predictability for stakeholders. It embodies the "adapt and learn" principle by treating uncertainty and new information as opportunities for improvement rather than barriers to action.

I.2 Implementation Challenges and Mitigation Strategies

Potential barriers and how to address them: Several challenges may arise during implementation of the MSE framework and alternative management approaches:

- **Governance and institutional barriers**:
  - Challenge: ICES advice processes may be slow to adapt to alternative reference points and frameworks.
  - Mitigation: Engage early with ICES working groups, present MSE results at ICES meetings, work within ICES guidelines while proposing innovations. Consider UK-specific advice if needed, while maintaining compatibility with ICES processes.
- **Data limitations**:
  - Challenge: Recreational catch data and economic data are currently limited, constraining MSE development and evaluation.
  - Mitigation: Prioritise recreational monitoring enhancement in short-term actions. Develop MSE framework incrementally, starting with biological metrics and expanding as data improve. Use sensitivity analysis to understand implications of data uncertainty.
- **Stakeholder resistance**:
  - Challenge: Some stakeholders may resist change from current MSY approach or disagree on priorities.
  - Mitigation: Early and transparent stakeholder engagement, clear communication of trade-offs, structured consensus-building processes. Emphasise that MSE provides evidence for decision-making but does not dictate outcomes.
- **International coordination**:
  - Challenge: EU partners may not adopt alternative approaches, limiting effectiveness of UK-only implementation.
  - Mitigation: Early engagement with EU partners through ICES, bilateral discussions, and shared MSE results. Explore coordinated implementation where possible, while recognising that UK can still benefit from improved management even if coordination is limited.
- **Resource constraints**:
  - Challenge: MSE development and enhanced monitoring require significant resources.
  - Mitigation: Phased approach allows incremental investment. Prioritise critical components (recreational monitoring, basic MSE framework). Seek funding from multiple sources (Defra, Welsh Government, research grants).

These challenges are not insurmountable, but they require proactive management and stakeholder engagement throughout the implementation process.

J Case-Specific Considerations for Bass and Alternative Approaches

This appendix gathers the technical ICES EQSIM/MSY reference-point mechanics and associated precautionary limitations that motivate the bass-specific, rebuilding-time-based approach described in the main report.

The ICES framework has been applied across many European fisheries. For bass, the relevant question is performance against broader FMP objectives adequate, not MSY consistency alone. For bass, as a mixed commercial–recreational fishery with specific characteristics, case-specific considerations include the use of hockey–stick stock–recruitment relationships, which for some stocks may produce biomass limits and triggers that are not risk–equivalent across stocks [17]. In some cases, the estimated hockey–stick breakpoint may lie close to B_{MSY}, such that using this breakpoint as B_{lim} may imply a "limit" reference point effectively at the target biomass, which may be conceptually inconsistent with the role of B_{lim} as a lower bound on acceptable stock status [1, 17]. The ICES framework allows for case-specific adaptation, and for bass alternative approaches can complement the ICES framework to address these considerations.

J.1 Technical detail: EQSIM-based ICES MSY reference points and precautionary limitations

Within ICES, F_{MSY} and associated reference points are generally derived using stochastic forward simulations (using the ICES Equilibrium Simulation method (EQSIM)) based on a benchmark assessment [46, 55]. A recent study showed, however, that if the full feedback between assessment, advice, implementation, and population dynamics is represented in a management strategy evaluation (MSE) framework, then the EQSIM–based F_{MSY} values frequently do not satisfy the Precautionary Approach criterion that the probability of spawning biomass falling below B_{lim} should not exceed 5% [3]. Reference points that are judged precautionary under the current ICES procedure may actually not be precautionary when evaluated using MSE, i.e. a realistic closed–loop simulation that incorporates assessment uncertainty, time lags, and implementation error [see also 62, 63].

For sea bass and other stocks, EQSIM implicitly assumes that for each candidate F there is a corresponding equilibrium biomass and yield, and the distribution of the simulated biomass. In reality, any given F can lead to a wide range of possible biomass trajectories once process error, assessment error and implementation uncertainty are accounted for. This may mean that even fishing below the target F_{MSY} can lead to stock depletion, and loss of older fish, requiring recovery plans to be an explicit part of any harvest strategy. This is a key stakeholder concern, i.e. that the ICES MSY Approach does not handle uncertainty in a genuinely precautionary way.

[3] showed a strong asymmetry between risk and yield: reducing fishing mortality to around 60% of the EQSIM–derived F_{MSY} leads to only a modest loss in long–term average yield (often less than 5%), while substantially reducing the risk of breaching B_{lim} and increasing average biomass [3]. This implies that treating F_{MSY} as a target, rather than as an upper bound, is not justified from either a precautionary or an economic perspective. This reflects the empirically "flat-topped" nature of the yield curve: large gains in resilience, ecosystem status and stakeholder benefits can be achieved at very limited cost in foregone yield. The current ICES MSY Approach effectively ignores this risk–benefit asymmetry by treating F_{MSY} as a target rather than as a precautionary upper bound.

A second, related limitation is that the current ICES MSY-based framework has focused primarily on regulating F, while largely neglecting explicit biomass and structural targets. For 73 Northeast Atlantic Category 1 stocks, Winker et al. [3] demonstrate that although median fishing mortality has been reduced to at or just below F_{MSY}, median biomass has only recovered to approximately $0.68\,B_{\text{MSY}}$, and only about 40% of stocks are currently above B_{MSY}. In practice, ICES typically reports and uses MSY B_{trigger} (often approximated as a multiplier of B_{lim}) as a biomass reference point and, operationally, as a surrogate for B_{MSY} [64, 47]. This leads to an over–optimistic classification of stock status: stocks can be labelled as "within safe biological limits" while still below B_{MSY} and therefore not meeting the biomass objectives of the Common Fisheries Policy (CFP), the Marine Strategy Framework Directive (MSFD), or the UK Fisheries Management Plans [3]. For a stock such as bass, where resilience to shocks, high catch rates, and the availability of large fish are central to stakeholder concerns, B_{MSY} itself is likely too low a target; a Large Fish Strategy (LFS) (e.g. biomass well above B_{MSY}) would better support both ecological resilience and the economic and social goals identified in the Bass FMP.

For sea bass, this means that the current ICES MSY-based framework, generally implemented through EQSIM-based reference points and the generic MSY advice rule [47], cannot be presumed to be precautionary, nor to deliver the biomass and rebuilding outcomes required by EU and UK policy, particularly given its importance to coastal communities across all sectors [e.g. 11]. Within the commercial sector, small-scale targeted fishers (hooks & lines) value a large, resilient stock with large individuals that delivers high catch rates (lower fuel costs and shorter trips) and, importantly, a high proportion of large individual fish with higher prices per kilo; bycatch fishers (trawlers, seiners, and fixed-net fisheries) benefit from improved stock availability and reduced regulatory constraints; and all commercial fishers benefit from a more resilient stock that supports sustainable livelihoods. Recreational fishers value a large, resilient stock with fewer blanks, more hook-ups and, crucially, more large trophy bass; recreational businesses value a dependable, high-quality fishing experience that drives participation and sales; and the wider public values a large, resilient bass stock as part of improving marine ecosystem health. All stakeholders in the UK will benefit from management that maintains a large resilient stock and a high proportion of large individual fish, yet none of these diverse priorities is explicitly addressed by the current ICES MSY Approach.

A review of the current ICES MSY-based framework for sea bass against Bass FMP objectives and the UK Fisheries Act 2020 led to the following conclusions:

EQSIM: For stocks with high uncertainty like bass, estimates of F_{MSY} may not always satisfy the nominal precautionary criterion that the probability of $SSB < B_{\text{lim}}$ should be less than 5%, once they are evaluated in a closed-loop MSE setting that includes realistic assessment error, implementation error and process uncertainty [see also 3, 62, 63]. Recent research also highlights the strong asymmetry between risk and yield: even where the 5% constraint is met in long-term simulations, F_{MSY} may be higher than would be required to truly maximise long-term yield, given that fishing at roughly $0.6 \times F_{\text{MSY}}$ yields almost the same long-term catch as F_{MSY} but with much lower risk. For bass, with high uncertainty in recreational removals and mixed-sector dynamics, additional precautionary testing in MSE frameworks may be valuable.

Benchmarks: for sea bass have produced large shifts in perceived stock status and reference points, with advised catches more than doubling between assessments (from 2,432 t to 5,180 t) primarily due to technical changes in assessment methodology rather than corresponding changes in underlying biology [9, 8]. This reflects the sensitivity of stock assessments to assumptions about natural mortality, stock–recruitment, recreational removals and spatial stock structure (single stock vs meta-population connectivity), and highlights the value of MSE testing to ensure harvest strategies remain robust across different assessment assumptions and reference point estimates.

The current MSY framework: The current ICES MSY-based framework has been applied across many European fisheries, particularly where objectives are framed around long-term yield and risk of biomass depletion. However, for bass as a mixed commercial–recreational fishery, the Bass FMP and Fisheries Act 2020 set out broader biological, socio–economic and ecosystem objectives that extend beyond MSY maximisation, including rebuilding times, distribution of benefits between commercial and recreational sectors, and broader ecosystem considerations. Section 1 therefore recommended that for bass, F_{MSY} should be treated at most as an upper bound, exploring alternative reference points based on rebuilding time, and moving towards ensemble modelling and MSE to represent uncertainty and evaluate candidate harvest strategies against multiple objectives, recognising that the ICES framework allows for such case-specific adaptation.

J.2 Rebuilding-Based Reference Points

Using a database of 82 Northeast Atlantic Category 1 stocks, Kell et al. [17] introduced rebuilding–based quantities B_{rebuild} and T_{rebuild} that explicitly characterise recovery trajectories. B_{rebuild} is defined as the lowest spawning biomass from which a stock can rebuild to a specified target biomass B_{target} within an agreed rebuilding timeframe T_{rebuild} under specified fishing conditions, while T_{rebuild} is the time required to rebuild from the current biomass to B_{target}. These analyses show that:

- stocks with nominally similar B_{lim} or MSY B_{trigger} can have very different rebuilding times, i.e. current reference points do not provide risk–equivalent control over T_{rebuild};
- rebuilding dynamics are driven primarily by the low–biomass region of the production function; and
- it is more biologically meaningful to calibrate limit and trigger points such that T_{rebuild} to B_{MSY} is of the order of one generation time (or a clearly specified policy horizon) than to rely on recruitment–impairment thresholds derived from historical data.

From a stakeholder perspective, the appeal of this approach is that it replaces abstract long–term equilibrium targets with explicit statements such as: "we aim to rebuild bass to B_{target} with robust size and age structure (Large Fish Strategy) within T_{rebuild} years with at least a specified probability". This directly answers questions about how quickly the stock will improve, how likely it is that biomass and structural targets will be met, and how different rebuilding strategies affect commercial and recreational opportunities along the way.

J.3 Age and Size Structure Indicators

A further weakness of current practice is that SSB is often treated as a sufficient proxy for reproductive potential, irrespective of age and size composition. Kell et al. [19] show that SSB alone can be a poor indicator of reproductive capacity when larger, older spawners are selectively removed: stocks with similar SSB but truncated age and size structure can have markedly reduced reproductive potential compared to stocks with a full complement of large fish. Building on this, Griffiths et al. [48] introduced an age–based indicator and corresponding reference point (ABI_{MSY}) that explicitly quantifies the contribution of older fish to stock status by comparing the current age structure of the stock with the equilibrium age structure at B_{MSY}, providing insight into demographic resilience. ABI_{MSY} would be tracked alongside SSB, with soft/hard bounds to indicate erosion of large–fish structure that should trigger review of measures. Together, these results emphasise that both biomass and the presence of older, larger fish are necessary to support robust reproductive potential and sustainable yields.

This concern about truncated size and age structure has gained significant policy attention at the EU level. The European Parliament's RecFishing Forum has explicitly linked marine recreational fisheries to the objective of restoring age and size structure in exploited stocks. A flagship example is the workshop "More big fish in the sea!" held in Brussels on 25 April 2023, co-chaired by MEPs Caroline Roose and Isabel Carvalhais, which highlighted how a narrow focus on yield-based MSY and TACs has coincided with truncated size and age structures in many EU stocks, leaving too few large, old fish. The workshop showcased age– and size–based indicators such as ABI_{MSY} and drew attention to the Marine Strategy Framework Directive descriptor on age and size distribution (D3C3), arguing that MSY should be complemented by explicit demographic structure objectives (age and size composition). This EU–level initiative reinforces the importance of incorporating large–fish protection and structural indicators into bass management, aligning with both scientific evidence and policy priorities at the European level.

J.4 Spatial Indicators

In addition, recent work on spatial indicators shows that changes in distribution, range and local density can provide early warning of depletion and may follow different trajectories during decline and rebuilding [49]. Candidate spatial metrics for bass include centre–of–gravity (tracking the geographic centre of biomass distribution) and the proportion of biomass inside historical core areas (e.g. key spawning or nursery grounds). Spatial contraction and delayed recolonisation can imply that stocks with apparently satisfactory SSB remain vulnerable and may not deliver ecosystem or fishery benefits across their historical range. For a coastal, mixed fishery such as sea bass, spatial indicators are therefore a critical complement to biomass and age–based metrics.

J.5 Implications for Sea Bass

For sea bass, where older and larger individuals make a disproportionate contribution both to reproductive output and to ecosystem and recreational value, and where availability along the coast is central to local communities, ignoring demographic structure (size and age composition) and spatial distribution risks overestimating resilience and underestimating the consequences of high F on the stock's ability to rebuild and sustain high productivity. These findings highlight a deeper conceptual issue with the current ICES MSY Approach as applied to sea bass: it is essentially long–term and equilibrium–oriented, with no explicit control over the time it takes for the stock to rebuild or recover from low biomass, and with inadequate attention to the age, size, and spatial structure that underpin true reproductive potential and resilience. For this stock, where stakeholders and policy makers care about short– and medium–term outcomes, the presence of large fish, and wide spatial availability, this omission is critical. It is not sufficient to aim for a large spawning stock biomass in an abstract long–term equilibrium that may never materialise; management must explicitly consider the pace and trajectory of rebuilding, and the maintenance of robust size and spatial structure, over realistic planning horizons.

K Observation Model: Data Types, Calibration, and Validation

K.1 Data Types and Error Structures

The Observation Model simulates the following data types with appropriate error structures:

- **Commercial landings and discards data**: Simulated catches with log-normal error, age/length composition sampling error, and potential misreporting or discarding patterns. Error structures should reflect historical variability in commercial catch reporting.
- **Recreational catch and effort estimates**: Simulated recreational removals with uncertainty reflecting current monitoring limitations. This should include both retained catch and catch-and-release, with appropriate error structures for shore recreational fishing, boat recreational fishing, and charter/guided sectors. The uncertainty should be calibrated to match the current data limitations identified in the benchmark assessment.
- **Survey indices**: Simulated survey data (e.g. Solent Bass Pre-Recruit Survey, Fal and Helford survey, Nourdem survey) with observation error, including year effects, age effects, and sampling variability. Survey catchability and selectivity patterns should be consistent with historical survey performance.
- **Age and length composition data**: Simulated age and length samples with multinomial sampling error, reflecting the sample sizes and sampling patterns used in the actual assessment. This includes commercial catch-at-age, survey age composition, and length-frequency data.
- **Stock assessment uncertainty**: The Observation Model should represent the full assessment process, including:
  - Retrospective patterns (systematic bias in terminal-year estimates)
  - Assessment convergence issues
  - Uncertainty in estimated quantities (SSB, F, recruitment) as revealed by variance–covariance matrices or bootstrap samples
  - Correlations between estimated SSB and F that affect HCR performance

K.2 Calibration

The Observation Model should be calibrated to match the performance of the current SS3 assessment, including:

- The ability to track true stock status (how well assessment estimates match Operating Model truth)
- The magnitude of assessment uncertainty revealed by retrospective analysis
- Historical patterns of assessment bias and convergence issues
- The correlation structure between estimated SSB and F that affects HCR decision-making

This calibration ensures that the MSE framework accurately represents the assessment process and its limitations, providing realistic evaluation of management procedure performance.

K.3 Full vs Shortcut MSE

For computational efficiency, shortcut MSE approaches using calibrated emulators (e.g. Gaussian-process surrogates) can be used for initial screening and parameter tuning. In shortcut MSE, the full assessment model is replaced by an emulator that injects structured error into the quantities used by the HCR (e.g. SSB, F), calibrated from analytical retrospectives or historical hindcasts.

However, for final advice provision, full MSE with the complete assessment model (or empirical indicators for empirical MPs) is required to ensure that emergent behaviours (e.g. convergence issues, retrospective bias, assessment failures) are properly captured. Shortcut approaches should be validated against full MSE results before being used for final decision-making. The choice between full and shortcut MSE should be made based on computational feasibility, assessment model complexity, and the need to capture emergent behaviours.

K.4 Validation Procedures

The MSE framework must be validated against historical data to ensure it accurately represents the bass stock dynamics and assessment process. This involves:

- **Retrospective testing**: Comparing simulated assessment results with actual outputs to verify that the Observation Model accurately represents the assessment process.
- **Hindcasting**: Validating that the Operating Model captures key population dynamics by comparing simulated historical trajectories with observed data.
- **Calibration of uncertainty**: Matching error patterns from retrospective analysis to ensure uncertainty is appropriately represented.
- **Sensitivity testing**: Ensuring robustness to key assumptions by testing alternative model configurations and parameter values.

The validated framework should then be used prospectively to evaluate candidate management procedures, with regular updates and re-validation as new data become available.

L Operating Model Conditioning Procedures

L.1 Conditioning Principles

In the MSE context, "conditioning" refers to choosing functional forms and parameterisations that are consistent with available evidence from the benchmark assessment and ecological theory, not simply using assessment results. For Category 1 stocks like bass (where a full stock assessment exists), conditioning involves:

- **Stock–recruitment relationship**: Choosing a functional form (e.g. Beverton–Holt, Ricker) that is consistent with the evidence from the assessment, historical data, and ecological theory. Note that segmented regression (hockey-stick) models are not biologically plausible as they assume abrupt productivity shifts, which poorly represents the gradual nature of recruitment processes. The choice of functional form affects productivity assumptions and reference point estimates.
- **Process error structure**: Specifying the form of process error (e.g. recruitment variability, environmental stochasticity) and its autocorrelation structure. The form of process error affects how uncertainty propagates through the system and influences the feedback control rule's performance.
- **Parameter uncertainty**: Representing uncertainty in key parameters (e.g. natural mortality M, stock–recruitment steepness h) based on assessment variance–covariance matrices, bootstrap samples, or Bayesian posteriors.
- **Fleet selectivity patterns**: MSY is not a purely biological concept—it depends critically on fleet selection patterns. Without selectivity constraints, the global F_{MSY} would be infinite. The Operating Model must represent fleet-specific selectivity patterns (commercial vs. recreational, different gear types) as these determine the relationship between fishing mortality and yield. Furthermore, MSY reference points are dependent on allocation across sectors (commercial vs. recreational, different gear types), and this allocation may change with factors such as relative stability (the historical allocation keys used in EU fisheries management), sector-specific management measures, or shifts in fishing effort between sectors. This means that F_{MSY} and B_{MSY} are not fixed biological quantities but depend on how removals are distributed across fleets and sectors, and the Operating Model must represent this allocation structure to accurately estimate MSY reference points.

L.2 Ensemble Construction

The framework builds on the base Operating Model by:

- Incorporating additional uncertainty scenarios (productivity, structure, spatial) not fully captured in the base assessment
- Exploring alternative hypotheses about stock dynamics, recruitment, natural mortality, and selectivity
- Setting up reference and robustness Operating Model sets as required by ICES guidelines
- Integrating sector-specific dynamics and management measures

M Validation and Calibration Procedures

Validation and calibration approach: The MSE framework must be validated against historical data to ensure it accurately represents the bass stock dynamics and assessment process. This involves:

- **Retrospective testing**: Running the MSE framework retrospectively over historical periods (e.g. 2000–2025) and comparing simulated assessment results with actual assessment outputs. This validates that the observation model and assessment process are correctly emulated.
- **Hindcasting**: Using the operating model to simulate historical stock trajectories and comparing these with assessment estimates of historical biomass and fishing mortality. This validates that the operating model captures key population dynamics.
- **Calibration of uncertainty**: Adjusting the magnitude of process error, observation error, and assessment error in the MSE framework to match the uncertainty patterns revealed by retrospective analysis of the SS3 assessment (e.g. retrospective Mohn's rho, assessment error variance).
- **Sensitivity testing**: Testing the sensitivity of MSE results to key assumptions (e.g. natural mortality, stock–recruitment steepness, recreational removals) to ensure the framework is robust and that uncertainty is appropriately represented.

The validated MSE framework should then be used prospectively to evaluate candidate management procedures, with the understanding that validation against historical data provides confidence but does not guarantee future performance under novel conditions (e.g. climate change, new fishing technologies). The framework should be regularly updated and re-validated as new data become available, supporting adaptive management and continuous learning.

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