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Unobserved Fishing Mortality Working Group

REPORT

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Introduction

The Unobserved Fishing Mortality Working Group (UFMWG) was formed in October 2023 in response to a SSC request and further Council endorsement following the presentation of a Crab Conservation Workplan in December 2022. Further, in June 2023, the Council developed objectives and end products for the UFMWG as detailed below:

The Council-approved objectives of the working group are as follows:

- *Identify data sources, major data gaps, and assumptions to estimate unobserved mortality for stock assessments and to better understand temporal/spatial extent across fisheries and gear types.*
- *Provide research priority recommendations and/or needed research projects.*

The anticipated products include:

- *Framework for estimating unobserved fishing mortality and explicitly incorporating estimates into stock assessments.*
- *Report on specific research priorities and data needs.*
- *Recommendations for approaches to investigate spatial/temporal extent of unobserved mortality over fisheries and gear types to the extent practicable.*

The interagency working group (WG), consisting of SSC and CPT members, and NOAA agency personnel, met virtually four times in two-hour increments across four weeks from October 2023 to November 2023. Over the span of the meetings, the WG broadly discussed each of the objectives and put forth recommendations. This report summarizes the discussion in four main sections: (1) a summary of the existing data that may be utilized to estimate unobserved fishing mortality (UFM), and relevant data gaps; (2) a framework for incorporating UFM into stock assessments; (3) UFM research priorities; and (4) the WG recommendations. Given the complexity associated with estimating UFM, the WG determined that it was most appropriate to discuss UFM in the context of the "big three" crab stocks: Eastern Bering Sea (EBS) snow crab, Bristol Bay red king crab (BBRKC), and EBS Tanner crab. While many of the topics discussed may be applicable to other federally managed crab stocks, the specific recommendations of this WG apply only to these three stocks.

The WG participants recognized that they did not represent the perspectives of the full CPT or SSC, and that further public discussion and review of all topics would be conducted through the January 2024 CPT meeting and subsequent SSC/Council reviews. The WG encourages members of the public and gear experts to provide public comment at these reviews to provide additional expertise that was not

encompassed by the WG membership. The WG recommendations highlight the approaches to estimating UFM and data and information gaps that constrain appropriate estimation of UFM, provide a framework for estimating UFM in stock assessments, and highlight research needs for filling UFM data and information gaps.

Magnitude of unobserved mortality as a function of gear type

The WG summarized current *observed* mortality estimates for four main gear types: pelagic trawl (PT), non-pelagic trawl (NPT), pot, and hook-and-line (HAL). These mortality estimates are derived from status quo Prohibited Species Catch (PSC) or stock assessment estimation procedures.

To establish a framework for comparing the potential magnitude of UFM among gear types and stocks, data availability, gear type interactions, and research needs across gear types, the WG created two tables that summarized the group's consensus on these areas as well as the WG's recommendations for prioritizing further research. Explicit reasoning for prioritization was based on both the potential for lethality as a function of gear type at the level of individual fishing events, and the potential for a population-level effect on crab stocks.

Table 1 details a draft of the information for UFM at the individual event and population levels as a function of gear type to summarize the data available and data gaps for estimating UFM. To estimate UFM, the WG determined that several areas of research are needed, including a better understanding of the spatial/temporal extent of fishing gear bottom contact, crab spatial distribution by size/life stage and season, crab movement, size and life stage-dependent vulnerabilities of crab stocks, the probability of encountering crab by gear type, and the subsequent mortality rate resulting from gear encounters (Table 1). Some of these areas are the subject of ongoing research, but these research projects are generally either in-progress or are not designed to directly inform UFM estimates. The WG emphasized that the gear types that currently lack research but may contribute to a higher magnitude of UFM are lost pots, NPT, and PT. The WG suggests research on bottom contact, event-level crab encounter rates, and lethality for these gear types be prioritized. At the population level, it is important to determine where overlap with crab may be occurring and the potential total number and/or duration of events (e.g., for lost pots; Table 1). Table 2 provides an approach for estimating the magnitude of UFM by gear type and provides a comprehensive summary of areas requiring additional research and prioritization.

While the two tables have some overlap, the WG found it helpful to identify the data gaps by gear type in Table 1 and to suggest the potential areas of research required to resolve the highlighted data gaps and establish research prioritization in Table 2. The rationale for the elements in the two tables is discussed in more detail below.

Assumptions and uncertainties to estimate unobserved fishing mortality

The WG broadly discussed the types of assumptions and uncertainties that are associated with estimating UFM. The WG highlighted four main elements required to assess UFM: (1) estimated bottom contact of all gear types; (2) spatial and temporal distribution of crab; (3) the probability of encounter rates based on (1) and (2) ; and (4) the resulting mortality of a crab-gear encounter. Information gaps associated with each of these four elements are identified in Table 1 under *Data Availability* and *Research Needed*, and further described in Table 2. The WG recognizes that there may be several additional assumptions that

were not discussed, given the complexity in estimating UFM. Table 2 suggests potential approaches to estimating UFM, identifies datasets that might potentially inform UFM estimates, highlights key assumptions required, and recommends areas for further research.

It is important to note that UFM resulting from crab-gear interactions is directly influenced by specific gear design, materials, and configuration. The WG notes that Pot, HAL, PT and NPT gear categories are broad and that within these categories, there is broad variability in design that will impact UFM. As such, a better understanding of the specific gear types interacting with crabs is crucial to estimating the probability of gear-crab encounters and subsequent mortality rates.

More comprehensive information on the spatial and temporal distributions of crab is required to make informed estimates of probability-of-encounter rates. Specifically, there is a lack of fishery-independent data to inform the spatial distribution of crab during the winter and spring. The WG highlighted recent efforts using NMFS bottom trawl survey data to predict crab catches in directed and bycatch fisheries outside the summer season, and the winter-spring 2023 Collaborative Pot Sampling (CPS1) project, as two approaches to better inform understanding of spatial and temporal distributions outside the data-rich summer season. The WG noted that seasonal habitat use and spatiotemporal crab life history information is a high priority for improving estimates of gear encounter rates and subsequent mortality probability.

The probability-of-encounter rates and subsequent mortality associated with encounters is an emergent area of research with many data gaps due to the sparsity of field experiments and the wide variety of gear configurations used. This is an area of high priority for research as these rates are critically important to estimating UFM. The WG agreed that the state of knowledge required for informed UFM estimation depends heavily on future field studies. Table 2 provides potential approaches to estimating encounter and mortality rates, which include the Fishing Effects (FE) model to estimate encounter rates, direct observations to estimate the ratio of typically unobserved to observed crab encountered by a given gear, and direct or indirect estimates of the mortality rates associated with these encounters.

Tools to estimate unobserved fishing mortality

The WG discussed the potential to use the FE model as a tool to estimate UFM. The FE model leverages Vessel Management System (VMS) data, observer data, and expert knowledge of fishing gears to estimate the spatiotemporal distribution of fishing gear bottom contact, and the resulting cumulative impacts to benthic habitat in the North Pacific region. The FE model has been used to assess the adverse effects of fishing on Essential Fish Habitat (EFH), as well as in several recent Council analyses investigating bottom contact as a way to infer potential gear interactions with crab stocks, such as BBRKC and EBS snow crab. The WG noted that while the FE model is a useful tool to estimate bottom contact from fishing events, it cannot inform the probability of gear encounters with crab species, or support UFM estimation without knowledge of crab spatiotemporal distribution and vulnerability to gear interactions. Therefore, while the FE model is a useful tool to characterize fishing activity and estimate habitat impacts, it cannot currently be used to assess UFM.

In addition to the FE model, there are several ongoing studies at the NMFS Kodiak lab intended to provide new information and insights in the areas of crab spatial and temporal distribution and crab life history. This work includes Species Distribution Models (SDMs) for BBRKC based on

fisheries-dependent data, an improved snow crab SDM to resolve sex- and maturity-specific distributions, a newly-funded project utilizing the FE model and SDMs to inform the joint distribution of bottom contact and crab which may elucidate the magnitude of unobserved mortality based on the potential frequency and intensity of crab-gear interactions, and (in collaboration with ADF&G and the Bering Sea Fisheries Research Foundation) analysis of BBRKC movement patterns from satellite tagging data. The WG was encouraged by these projects and notes that it may be some time before they produce information products suitable to inform UFM.

Framework for Incorporating Unobserved Fishing Mortality into Stock Assessments

Current Tier 3 assessment methodology for observed fishing mortality

The WG summarized the current approach to incorporating mortality into assessments. For the "big three" stocks, the assessment methodology includes estimates for natural mortality (M) and fishing mortality (F), where M may vary by sex and maturity state but is typically assumed to be constant over time, except in some cases to account for 'mortality events'. In contrast, F varies by sex and size, as well as over time, as it is fit to observed or estimated annual catch data (biomass and size composition) that includes retained and total catch in the directed fisheries and bycatch (discards) in other fisheries. Size- and sex-dependent selectivity functions are applied for each fishery and may change over time.

The WG discussed two key processes in the assessment models that would be affected by including UFM: (1) time series of estimated recruitment, and (2) estimates of overall mortality. Recruitment estimates from the assessment models currently encompass any UFM experienced by small (pre-recruit) crab. Importantly, the current assessment models do not track crab below the minimum size at which different crab species are effectively sampled by the NMFS survey gear. Hence any UFM for crab below these size thresholds would simply result in reduced recruitment estimates but would not be attributed to UFM in the models. The WG suggested that authors could link recruitment in an assessment model to one or more covariates that reflect variability in the spatial overlap between different fleets and juvenile crab over time (e.g. gear-specific fishing effects model outputs) to estimate this effect. This approach could potentially provide estimates of the proportion of recruitment variability that may be associated with fishing impacts and could be used in further impact analyses.

The WG further discussed the idea that incorporating UFM into the assessment models for post-recruit crab would require that mortality be decomposed into natural mortality (M), fishing mortality (F), and unobserved fishing mortality (U), with each tracked for different components of the population (such as by sex, maturity state, shell condition, and/or size class). The WG discussed a potential framework to incorporate UFM into assessment mortality, as described in the section below.

Potential approaches to include unobserved fishing mortality

The WG discussed how best to include U in assessment models and discussed the information required for authors to incorporate new estimation methods for mortality. The WG concluded that if an additional term is included for U, it would have to be tracked by gear and potentially applied to specific components of the population (i.e., size, sex, maturity state, and shell condition), that would likely be species-specific.

The WG suggested two ways to incorporate UFM into assessments. In one possible approach, *U* could be parameterized for each gear as the product of a 'scaling' parameter, a bottom contact index, and a relative 'vulnerability' for different components of the population (size, sex, etc). The bottom contact index would be estimated from the FE model or other similar approaches to reflect encounter rates that would vary across years (or over finer time scales). The scaling parameter would be estimated externally or in the assessment model to reflect the overall gear impact, while the vulnerability term would reflect the relative vulnerability across different stages, size classes, etc. This could be incorporated in the model as either an additional mortality term (*U*) or as an additional 'fleet'. If considered as an additional mortality term, the UFM component would either specify or estimate time-varying mortality that would be a function of the gear-specific bottom contact indices, possibly summed across gear types. In the 'gear-as-fleet' approach, the vulnerability terms would be fit to data, requiring 'observations' (independent estimates) of UFM by gear type or by gear type and category (sex, size, etc.).

The general framework outlined above may serve as a way to explore the consequences of, and perhaps incorporate, UFM in the assessment. However, to account for additional unobserved mortality, the model would have to be fit to new data on UFM, which are currently unavailable. In the absence of new data, the model would simply fit additional gear-specific scaling parameters to better fit the existing data. Thus, at least initially, the primary utility of this approach may be in a research model to explore possible consequences of unobserved mortality in the model. The approach of incorporating UFM as an additional mortality term would provide an appropriate research framework until data on UFM become available to inform the proposed fleet-based approach.

The WG also discussed a simpler approach that would incorporate independent estimates of UFM into the model, similar to the approach currently used to incorporate observed bycatch mortality in assessment models. This could be implemented similarly to previous explorations that "inflated" observed bycatch by a multiplier to explore the resulting effects on management reference points, as a way of estimating the range of possible population-level impacts of hypothesized increases to bycatch mortality. This approach could be refined based on additional field experiments to estimate the ratio of unobserved to observed encounters by gear type and crab size. The model would then be fit to the sum of observed bycatch mortality plus estimated UFM, but would also require independent estimates of the probability of mortality following gear encounters, which could be included using a similar approach to that currently used to treat handling mortality in the assessment models. It was noted that this approach may ultimately be very similar to the proposed fleet-based approach, but without the explicit estimation of gear-specific scaling parameters.

The WG agreed that assessment authors could explore incorporating UFM into assessments based on the suggested methods. However, most of the data to inform these modeling approaches does not yet exist, so incorporating UFM into assessment models is unlikely to occur in the near term.

It is important to note that there is substantial variation among assessment models, and feasible approaches for UFM will likely vary from stock to stock. Any approach that is implemented to incorporate UFM in assessment models would undergo the normal review process before the CPT and SSC. Assessments incorporating UFM would require approval from both Council-advisory bodies before being used for management purposes (i.e., determining harvest specifications).

Unobserved Fishing Mortality Research Priorities

The WG emphasized that estimating UFM for all gear types is a high priority, but acquiring the necessary information will require substantial research effort. The WG constructed Tables 1 and 2 to explore data availability and highlight potential priority areas for research to inform UFM estimation. It is important to note that these tables were populated using the perspectives and opinions of the WG members and are not the result of a literature review or a formal evaluation of expert knowledge. Table 1 summarizes the current state of knowledge for four elements of a UFM analysis (see the Assumptions and Uncertainty section above) and captures the WG's perspectives on assumptions necessary to inform UFM by gear type and associated uncertainties in the *data availability* and *research needed* fields. Table 2 provides additional insight into the potential approaches, priority level, and likely timeline for additional research needed to inform UFM estimation. Table 2 is not comprehensive and may not include all research areas necessary to quantify UFM, but rather provides a research baseline the WG feels is necessary to inform UFM estimates.

Owing to the myriad data and information gaps associated with all four elements of a UFM analysis, the WG could not prioritize the importance of UFM from one gear type over another. However, the WG was able to prioritize individual research needs at both an individual event level and the population leve.. When prioritizing research needs for different gear types, the WG considered the following criteria: estimated bottom contact, time on bottom, the expected lethality of gear, overlap with crab, and the expected ratio of unobserved to observed mortality for each gear. Each of these criteria is included as a column in Table 1, except for the unobserved:observed mortality ratio. The WG determined that for most of the considered gear types there was either no information for this ratio, or that relevant information was addressed in other columns, so any pertinent points about the unobserved:observed ratio are made in the text of this report rather than in Table 1.

From the WG's initial prioritization, the gear types exhibiting the highest priority (Med-High) for additional research are: lost pots, NPT, and PT. Specifically, NPT and PT warrant additional research in the areas of bottom contact, gear lethality, and the potential for events to overlap with crab to produce population-level impacts. The WG identified work on the lethality of PT gear as the highest priority for additional research (Table 1). This prioritization was motivated in part by the expectation that PT gear has the potential for a relatively high ratio of unobserved:observed encounters with crab. The WG suggested research approaches and identified likely research timelines for work on mortality rates for all gear types. The WG discussed the potential for in-situ video sampling approaches, including forward-looking cameras to detect crab-gear encounters and video sampling of trawl paths to assess lethality (Table 2).

The WG also identified crab spatial and temporal distribution by size and life stage, as well as size/life stage-dependent vulnerabilities, as additional high-priority research topics (Table 2). These topics are a high priority for all gear types, as this information informs one of the key elements (crab distributions) necessary to inform UFM estimates. In addition, the WG identified two areas of high-priority research that could likely be completed on a shorter time frame. These include information on size- and life-stage-dependent vulnerabilities in crabs, and improved information on the bottom contact or footprint of all fishing gears to improve contact ratio estimates (Table 2). For most of the remaining research priorities, work would either require new initiatives over a longer time frame or work is currently

underway but will require several years before results are ready to incorporate into estimations or modeling frameworks.

Working Group Future recommendations

The WG has taken the first step in achieving the Council's requested end products of developing a framework for estimating unobserved fishing mortality and explicitly incorporating those estimates into stock assessments (See *Framework for Incorporating UFM into stock assessments above*), reporting on specific research priorities and data needs (Table 2), and making recommendations for approaches to investigate the spatial/temporal extent of unobserved mortality over fisheries and gear types to the extent practicable (Tables 1 and 2). The WG emphasizes that substantial data deficiencies currently preclude meaningful estimation of UFM. Overcoming these data gaps will require that all of the data gaps and research needs outlined in Table 1 be addressed. The end products provided in this report constitute a substantial effort by WG members to summarize the current state of knowledge around UFM, and provide a systematic prioritization of the research necessary to best estimate UFM for utilization in a management setting. The WG notes that the construction of robust research designs depends on ecological or biological evidence (even preliminary) that elucidates the mechanisms and magnitude of a particular phenomenon of interest. The WG discussed this briefly, noting that further refinement of UFM research recommendations and an assessment of the relative priority of UFM research versus other areas of study (e.g., climate impacts on population dynamics) would benefit from such evidence.

The WG agreed that further working group meetings would likely not be fruitful until additional research was completed to fill in some of the identified data gaps. Should the Council suggest additional meetings, it is the WG's recommendation that these meetings include a broader range of experts, such as gear experts or industry personnel, to fill in some knowledge gaps. The WG encourages members of the public and industry personnel to participate in the ongoing discussion at the January 2024 CPT meeting and June (T) 2024 SSC/AP/Council meetings.

Table 1. Draft summary information of Unobserved Fishing Mortality (UFM) at the Individual Event and Population Levels as a function of gear type. Information types include an estimated Score/Category, whether data are currently available, the general type of research that is needed, a proposed priority for that research, and an estimated timeline to undertake the needed research. Information needed to estimate UFM at the Individual Event level includes Bottom Contact, Time on Bottom, and "Lethality" of the fishing gear. Additionally, at the regional level, estimates of the total number of fishing events and the overlap between fishing and crab distributions ("Crab Dist.") are needed to estimate the overall impact of UFM. The number of different gear configurations for each gear type reflects the current number of gear types in the Fishing Effects Model gear tables, and indicates our recognition that important variability may exist within the gear type categories used in this table. Order of magnitude values for the Bottom contact area and Total number of events are derived from 2019 Fishing Effects Model outputs for the Bering Sea. Highlighted cells show where the WG suggests research be focused due to either the amount of time required to obtain data and/or where improved estimates would be helpful.

Gear Type (# of configs)	Information Type	Individual Event (e.g., pot/trawl) Level			Population Level	
		Bottom Contact Area	*Time on Bottom*	*"Lethality" of gear*	*Total # of Events (pot lifts/trawls)*	*Overlap with Crab*
Pots (2)	*Magnitude*	10^1 m^2	Hours to Days	High	10^5	High
	Data Available	Yes	Yes	No	Yes	Yes
	Research Needed	Data mining	Data mining	Field exp'ts	Data mining	Data mining
	Priority	Low	Low	Low	Low	Low
	Timeline (years)	0.5-1	0.5-1	3-5	0.5-1	0.5-1
Lost Pots (2)	*Magnitude*	10^1 m^2	Months to Years	Medium	Unknown	High
	Data Available	Yes	Some	Some	Some	Some
	Research Needed	Data mining	Field expt's	Field expt's	Data mining/Field expt's	Data mining
	Priority	Low	Medium	Medium	Medium	Low
	Timeline (years)	1-2	3-5+	1-3	3-5	0.5-1
Hook-and-Line (3)	*Magnitude*	10^4 m^2	Hours to Days	Low	10^4	Medium
	Data Available	Yes	Yes	No	Yes	Some
	Research Needed	Data mining	Data mining	Field expt's	Data mining	Crab Dist.
	Priority	Low	Low	Low	Low	Low
	Timeline (years)	0.5-1	0.5-1	3-5	0.5-1	0.5-1
Non-Pelagic Trawl (13)	*Magnitude*	10^6 m^2	Minutes	High	10^4	Medium
	Data Available	Yes	Yes	Some	Yes	Some
	Research Needed	Data mining	Data mining	Field Exp'ts	Data mining	Crab Dist.
	Priority	Medium	Medium	Medium	Low	Medium
	Timeline (years)	0.5-1	0.5-1	3-5	0.5-1	1-5
Pelagic Trawl (30)	*Magnitude*	10^5 m^2	Minutes	High	10^4	Medium
	Data Available	Yes	Yes	No	Yes	Some
	Research Needed	Data mining	Data mining	Field Exp'ts	Data mining	Crab Dist.
	Priority	Medium	Medium	High	Low	Medium
	Timeline (years)	0.5-1	0.5-1	3-5	0.5-1	1-5

Table 2: Information needs, approaches, data availability, limitations, and research needs for assessing unobserved fishing mortality of crab in the Bering Sea. Shading indicates the relative prioritization of topics and potential approaches with the darkest gray = highest priority, lightest gray = lower priority, although still a requirement to estimate the magnitude of UFM. Many of the priorities highlight information needed to adequately address the priorities in Table 1.

Information Need	Approach	Available data/inputs	Key limitations (data & models)	Research needs
Bottom contact (footprint of fishing gears)	Fishing Effects model (all fisheries/gear types)	Catch-In-Areas database, based on VMS & observer data	uncertain estimates of 'effective' bottom contact, switch to EM may affect accuracy	Improved contact ratio estimates; sensitivity to model assumptions
	SDM approach to model distribution of ghost pots	Some empirical data for ghost pots (log book data)	'Effective area' unknown & dependent on crab movement	Direct observations (video)
Crab spatial distribution by size or life stage and season	Species Distribution Models (SDMs) such as GAMs, VAST, etc.	Summer bottom trawl surveys (EFH analyses & maps)	Summer distribution only	Surveys in other seasons
		BSFRF small mesh trawl surveys	Few years of data, summer only	Integrate with SDMs of summer distribution
		Winter Cooperative Pot Survey (CPS) for Red King Crab	Spatially restricted	SDMs of winter distribution; additional winter surveys
		Fishery-dependent CPUE (incl. bycatch 'CPUE' in groundfish fisheries)	Sampling effort not independent of crab distribution, limited footprint of fishery	Models appropriate to fishery-dependent CPUE & combining data from multiple fisheries
Movement (relative to stationary gear, ghost pots)	Movement models	Tagging data (e.g. RKC)	Sparse data, large cab only	Integrating movement into SDMs when possible
	Infer movement from SDMs	combine fishery-dependent & independent data	limited seasonal & spatial coverage to infer movement	Improved models for combining multiple, disparate data sources
Size / life stage dependent vulnerabilities	Vulnerability assessment	Literature review, assumed high during molting	limited information on relative vulnerability at different life stages	Timing and location of molting

	Use size as proxy for vulnerability	Spatial distribution by size class over the observed size range	Distribution & habitat requirements for recently settled juveniles	Vulnerability of small crab to fishing impacts
Encounter rate	Mechanistic: FE impacts model	Fishery footprint + SDM results on distribution of crab	Uncertainty associated with inputs	Distribution of crab during fishing seasons
	Empirical: Ratio of unobserved / observed encounters	Rose et al under-bag experiments	few experiments, likely high variability across gear configurations	Experiments / direct observations (all gear types & configurations)
Mortality rate (when encountered)	Under-bag experiments	Rose et al (some NPT gear)	Mortality difficult to assess	Experiments / direct observations (all gear types & configurations)
	High volume tagging experiments	None	Study design - feasibility of estimating M and disentangling mortality sources	Simulations to assess effectiveness and sampling effort needed
	Video observations	Limited observations from experimental fishing	Visibility, assessing injury & long-term mortality risk visually	Forward-looking cameras on trawls + independent video observations in trawl pass
	Assess escape mechanism effectiveness	ADF&G reports (AI GKC) Literature	Variety of pot types & escape mechanisms	lab experiments on degradation rates & force needed to escape
	Pop Dy model with M linked to modeled encounters	Modeled encounter rates by stock (FE model)	Model complexity is expensive; model does not account for small crab	Develop research models for Tanner and snow crab; begin exploring modeling approaches and information needs
	Pop Dy model with R linked to modeled encounters	Modeled encounter rates by stock (FE model)	Unlikely to provide estimates of mortality of small crab	Research models to explore potential impacts on recruitment

Abbreviations:

BSFRF = Bering Sea Fisheries Resarch Foundation	EM = Electronic Monitoring	M = Mortality	SDM = Species Distribution Model	
CPUE = Catch-per-unit-effort	FE = Fishing Effects	R = Recruitment	VAST = Vector Autoregressive Spatio-Temporal model	
EFH = Essential Fish Habitat	GAM = Generalized Additive Model	RKC = Red King Crab	VMS = Vessel Monitoring System	