# 1 Additional Figures

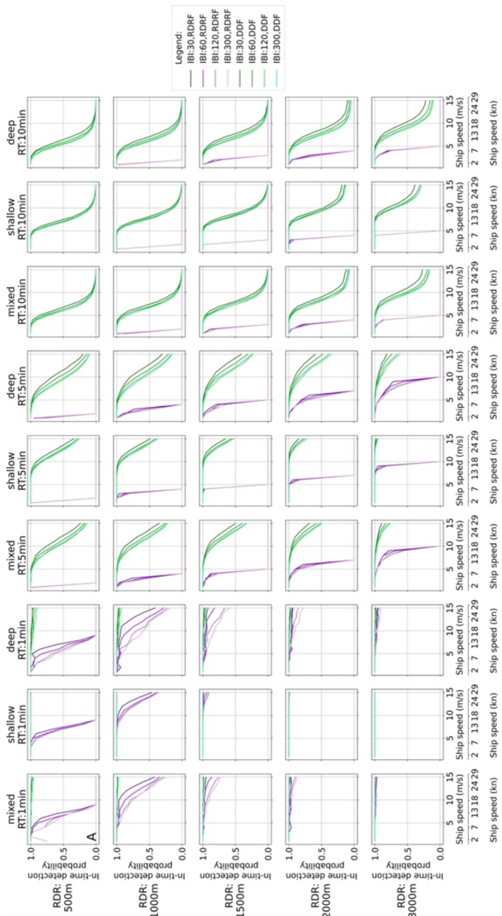

Figure S1. Comprehensive ITDP results for all modelled parameter combinations and varying ship speeds (m/s)

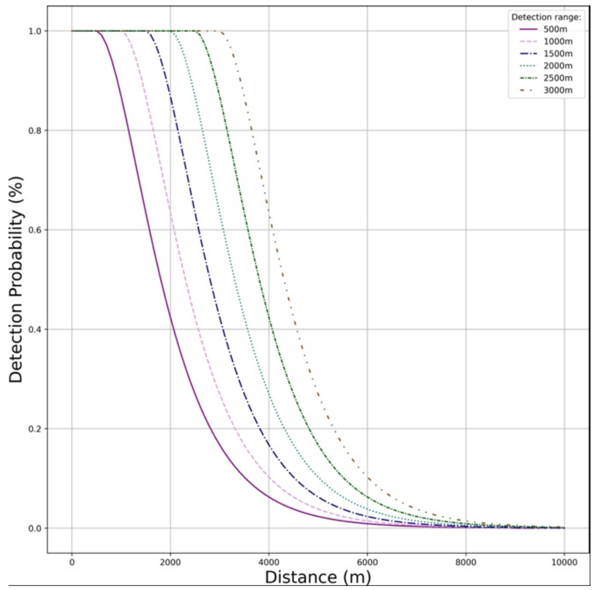


Figure S2. Detection Function as a function of distance (m) from the ship and detection range (m)

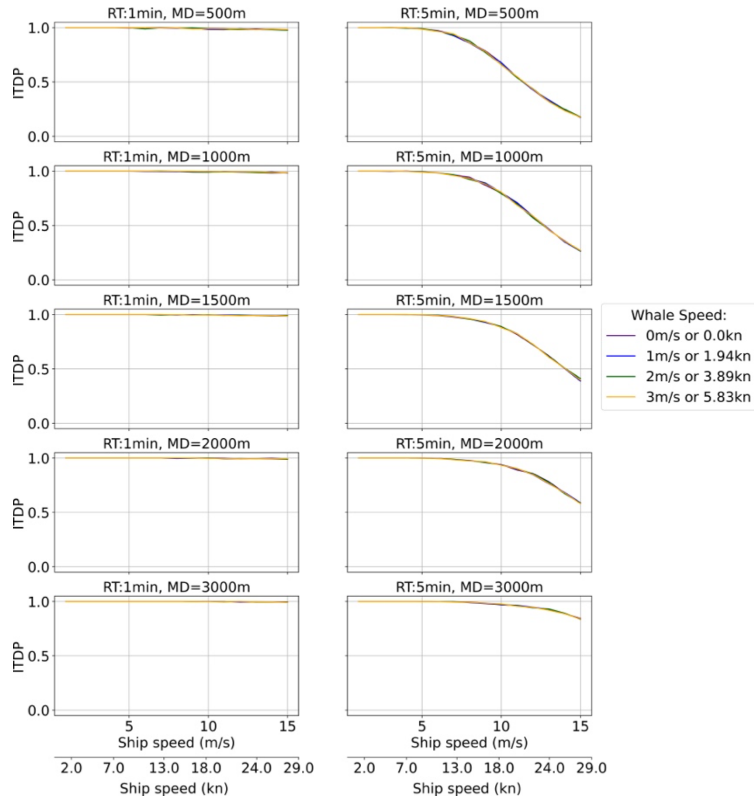


Figure S3. Comprehensive results of ITDP as a function of ship speeds (m/s) for varying whale speeds (m/s)

## Text S1: Large-Scale vessel strikes mitigation strategies

During the last decades a variety of mitigation measures have been developed to reduce the probability of vessel strikes. Vessel strike mitigation approaches can be classified into either large-scale approaches, where high-risks areas are established and a set of navigation rules are implemented, and small-scale approaches, that rely on vessels to detect at-risk animals and subsequently alter their course and speed to avoid collision. It is to be noted that marine mammal observations from vessel-based methods can always be used to in- form large-scale mitigation efforts about the presence of an animal at a given location and time. In the following, we will provide a brief overview of the existing mitigation efforts for North Atlantic right whales.

### Text S1.1: Re-routing

Rerouting aims to separate vessels from areas that are highly used by NARWs. Once high-risk regions are established, alternative vessel routes may be created to avoid such areas. Routing measures may be permanent, seasonal, mandatory or recommended, and may apply to all vessels or only a subset (Schoeman et al., 2020). Currently the following implementations of re-routing are used:

**Area To Be Avoided (ATBA)** ATBAs discourage vessels from transiting through certain areas of the ocean. Specifically, the International Maritime Organization (IMO) defines an ATBA as “a routeing measure comprising an area within defined limits in which either navigation is particularly hazardous or it is exceptionally important to avoid casualties and which should be avoided by all vessels, or certain classes of vessels” (Deepwater Port Act of 1974, 1974). Seasonal ATBAs in the Great South Channel, Cape Cod Bay, MA and Roseway Basin, Canada were established to protect North Atlantic Right Whales (Vanderlaan & Taggart, 2009).

**Dynamic Management Areas (DMAs)** In the US, voluntary DMAs, also called Slow Zones, are discrete areas established by NOAA Fisheries, where visual sightings of three or more North Atlantic right whales have been recorded within 15 days (Asaro, 2012). Mariners are encouraged to avoid these temporary areas or reduce their speed to 10 knots or less when transiting through them to avoid vessel strike (Asaro, 2012). NOAA created the Right Whale Sightings Advisory System to collect, validate, and communicate visual sightings reported by individuals. Those reports may also be used to establish new DMAs (Johnson et al., 2020).

**Seasonal Management Areas (SMAs)** When passing through SMAs, all vessels 65 feet (19.8 meters) or longer must travel at 10 knots or less, along the U.S. east coast (Cape Cod Bay, off Race Point, Great South Channel), at certain times of the year to reduce the threat of vessel collisions with endangered North Atlantic right whales (Code of Federal Regulations, 2014). van der Hoop et al. (2015) observed that large whale mortalities due to vessel strikes decreased when SMAs are active compared to when SMAs are not active (van der Hoop et al., 2015).

**Traffic Separation Schemes (TSSs)** TSSs are routing measures that separate opposing streams of traffic through the establishment of traffic lanes. Some of these permanent mandatory routes have been amended to reduce the co-occurrence of vessels and whales (Santa Barbara Channel, San Francisco Bay, Bay of Fundy (Canada), Boston) (Schoeman et al., 2020).

## Text S1.2: Speed restrictions

It has been shown that reducing vessels’ speed decreases vessel strikes’ rate and the injuries’ severity (Vanderlaan & Taggart, 2007; Gende et al., 2011; Conn & Silber, 2013). Laist et al. (2001), and later Conn and Silber (2013), showed that the probability of lethal injury decreased to lower than 50% when traveling at speeds ≤10 knots. In both studies, the vessel strike rate also decreased for lower vessel speeds. Proposals for speed restrictions can be submitted to the International Maritime Organization to implement, voluntary or mandatory, permanent or seasonal, vessel speed restriction zones outside of territorial waters (Silber et al., 2012). A reduction in vessel speed is the preferred measure to implement when vessels cannot be re-routed (Schoeman et al., 2020).

## Text S2: Small-Scale vessel strike mitigation strategies

The desired vessel strike mitigation measure would be applied on an individual vessel basis, where each transiting vessel would be in charge of detecting at-risk animals and react accordingly, by slowing down and changing its course to minimize the risk of vessel strike (Weinrich et al., 2010; Flynn & Calambokidis, 2019). Such mitigation measures can be implemented on-top of large-scale mitigation strategies or independently (Wiley et al., 2016).

## Text S3: Detection Methods

In order to establish high-risk areas and/or to implement small-scale mitigation measures, a multitude of methods have been developed to detect large marine mammals.

### Text S3.1: Passive Acoustic Monitoring (PAM)

PAM capabilities have massively improved over the last two decades as acoustic monitoring overcomes some of the limitations visual monitoring faces, such as bad weather (Verfuss et al., 2018). PAM relies on underwater micro- phones, hydrophones, to detect, classify and/or localize marine mammals' vocalizations, from a few hundred meters away to several kilometers depending on the environmental condition and species' vocalization frequencies (Verfuss et al., 2018). Hydrophones can either be permanently moored down or towed by a vessel (Verfuss et al., 2018). The latter system, which is com- monly used in seismic surveys, is not suitable for small-scale vessel strike mitigation approaches due to the logistical effort of towing hydrophone systems capable of detecting animals vocalizing in front of the vessel (Verfuss et al., 2018). On the other hand, moored PAM systems, in the form of auto- detection buoys with hydrophones located 60-120ft below the surface, have been implemented in the Port of Boston, Cape Cod Bay, the coasts of Georgia and Florida (Baumgartner et al., 2019) and constantly listen for NARWs calls. They send potential detections to a command-and-control center where trained analysts validate the sound. If the call is within 5-nautical miles of the buoy, alerts are sent out via radio, email, online (Right Whale Listening Network) to LNG tankers with re-routing or speed reduction instructions (Lippsett, 2009). However, PAM relies on animals to vocalize frequently and on background noise to be low enough to not interfere with vocalizations (Zitterbart et al., 2020). Hence, this method can lead to varying results due to environmental conditions, equipment, deployment types and target species (Verfuss et al., 2018).

### Text S3.2: Active Acoustic Monitoring (AAM)

Active acoustics has successfully been implemented to detect marine mammals up to 2000 m in front of a vessel via active sonars (Pyc et al., 2015). This technique emits pulses of sounds and records returning echoes to localize objects. Active acoustic methods inadvertently increase noise levels in the water, which can be detrimental to marine species

(André et al., 2011) and performance highly varies with the prevalent sound propagation conditions.

## Text S3.3: Radio Detection and Ranging (RADAR)

RADAR systems emit electromagnetic waves, and record for returning echoes to determine size, shape, distance, and speed of a target. RADAR technology aims to detect surface targets such as an animal body part, exhalations or sea surface disturbances (Verfuss et al., 2018). It operates best at detection ranges under a kilometer and at low sea state conditions as the shorter wavelength of electromagnetic waves are rapidly absorbed by water molecules (Verfuss et al., 2018).

## Text S3.4: Marine Mammal Observers (MMOs)

Manual detection of marine mammals via dedicated observers is still the most prevalent method used for any mitigation purposes (Weinrich et al., 2010; Zitterbart et al., 2020). Trained marine mammal observers scan the ocean surface surrounding the vessel, up to 5000 m, for potential sightings (Pyc et al., 2015). They have been shown to be more likely to detect animals than other crew members thanks to their experience and their lack of distractions from other factors (Weinrich et al., 2010). Weinrich et al. (2010) found that trained marine observers significantly increased the number of sightings on high-speed vessels and effectively prevented vessel strikes. During their study's time frame, the ferry using a dedicated MMO did not experience any strikes, while a similar boat without MMOs, transiting through the same route, collided with a fin whale (Weinrich et al., 2010). However, marine mammal observers are impacted by weather conditions and can only work at night in conjunction with night vision goggles, which greatly reduces the effectiveness (Schoeman et al., 2020).

## Text S3.5: Thermal Infrared Imaging (Thermal IR)

Thermal IR scanners are passive imaging systems that can be used day and night, on land (Zitterbart et al., 2020) and vessels (Zitterbart et al., 2013). They rely on an apparent temperature difference between the above-surface body parts of the animal or its exhalation and the ocean. Thermal IR systems have been shown to detect large whales reliably up to several kilometers away (Zitterbart et al., 2020).

# Table S1. Comprehensive list of parameters used for each run

| Case Description | Case # | Epoch Number | Run Time (s) | Grid Width (m) | RDR (m) | Ship Number | Ship Speeds (m/s) | Ship Heading (deg) | Angle of Detection (deg) | DDF | Ship Re-action Time #1 (s) | Ship Re-action Time #2 (s) | Ship Re-action Time #3 (s) | Whale Number | Mean Whale Velocity (m/s) | Std Whale Velocity (m/s) | Inter-Blow Interval (s) | All Whales Blowing | All Whales Surface | All Whales Subsurface | All Whales Deep | Dive Profile Mode |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SC Allblowing** | case1 | 50 | 3600 | 4000 | 1500,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 0 | 0 | 60 | 1 | 0 | 0 | 0 | mixed |
| **SC Allsurf** | case2 | 50 | 3600 | 4000 | 1500,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 0 | 0 | 60 | 0 | 1 | 0 | 0 | mixed |
| **SC Allsub** | case3 | 50 | 3600 | 4000 | 1500,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 0 | 0 | 60 | 0 | 0 | 1 | 0 | mixed |
| **SC Alldeep** | case4 | 50 | 3600 | 4000 | 1500,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 0 | 0 | 60 | 0 | 0 | 0 | 1 | mixed |
| **WhaleSpeed 0** | case5 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 0 | 0 | 60 | 0 | 0 | 0 | 0 | mixed |
| **WhaleSpeed 1** | case6 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | mixed |
| **WhaleSpeed 2** | case7 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 2 | 0.2 | 60 | 0 | 0 | 0 | 0 | mixed |
| **WhaleSpeed 3** | case8 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 3 | 0.2 | 60 | 0 | 0 | 0 | 0 | mixed |
| **IBI 30 DDF mixed** | case9 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 30 | 0 | 0 | 0 | 0 | mixed |
| **IBI 60 DDF mixed** | case10 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | mixed |
| **IBI 120 DDF mixed** | case11 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 120 | 0 | 0 | 0 | 0 | mixed |
| **IBI 300 DDF mixed** | case12 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 300 | 0 | 0 | 0 | 0 | mixed |
| **IBI 30 DDF mixed** | case13 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 30 | 0 | 0 | 0 | 0 | mixed |
| **IBI 60 DDF mixed** | case14 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | mixed |
| **IBI 120 DDF mixed** | case15 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 120 | 0 | 0 | 0 | 0 | mixed |
| **IBI 300 DDF mixed** | case16 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 300 | 0 | 0 | 0 | 0 | mixed |
| **IBI 30 DDF shallow** | case17 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 30 | 0 | 0 | 0 | 0 | shallow |
| **IBI 60 DDF shallow** | case18 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | shallow |
| **IBI 120 DDF shallow** | case19 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 120 | 0 | 0 | 0 | 0 | shallow |
| **IBI 300 DDF shallow** | case20 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 300 | 0 | 0 | 0 | 0 | shallow |
| **IBI 30 DDF shallow** | case21 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 30 | 0 | 0 | 0 | 0 | shallow |
| **IBI 60 DDF shallow** | case22 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | shallow |
| **IBI 120 DDF shallow** | case23 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 120 | 0 | 0 | 0 | 0 | shallow |
| **IBI 300 DDF shallow** | case24 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 300 | 0 | 0 | 0 | 0 | shallow |
| **IBI 30 DDF deep** | case25 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 30 | 0 | 0 | 0 | 0 | deep |
| **IBI 60 DDF deep** | case26 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | deep |
| **IBI 120 DDF deep** | case27 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 120 | 0 | 0 | 0 | 0 | deep |
| **IBI 300 DDF deep** | case28 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 0 | 60 | 300 | 600 | 100 | 1 | 0.2 | 300 | 0 | 0 | 0 | 0 | deep |
| **IBI 30 DDF deep** | case29 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 30 | 0 | 0 | 0 | 0 | deep |
| **IBI 60 DDF deep** | case30 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 60 | 0 | 0 | 0 | 0 | deep |
| **IBI 120 DDF deep** | case31 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 120 | 0 | 0 | 0 | 0 | deep |
| **IBI 300 DDF deep** | case32 | 50 | 3600 | 4000 | 500,1000,1500,2000,3000 | 3 | 1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15 | 90 | 20 | 1 | 60 | 300 | 600 | 100 | 1 | 0.2 | 300 | 0 | 0 | 0 | 0 | deep |

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