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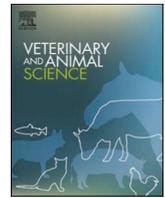
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Short Communication

A preliminary assessment of indirect impacts on aquaculture species health and welfare in Scotland during COVID-19 lockdown.

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ABSTRACT

COVID-19 led to sudden changes in human activities, mainly due to restrictive measures required to suppress the virus. We assess the preliminary evidence for impacts on animal health and welfare in Scottish aquaculture, a key economic activity in remoter areas of the country. We summarise the industry structure, explore pathways of vulnerability to aquatic animal disease within a One Health framework that may be accentuated by impacts of COVID-19, and use basic routine data collection on the key welfare indicators of salmon mortality and parasitic sea lice counts. The indicators were published on schedule and provide no evidence of gross impact on health and welfare, at least for salmon, during the period of intensive lockdown restrictions in Scotland. Longer term effects cannot be ruled out and we do not assess impacts on the economic or social aspects of aquaculture production.

Introduction

COVID-19 has caused widespread issues to human health and major disruption to the global economy. The global response has varied with many jurisdictions implementing travel bans, physical distancing and good hygiene measures alongside changes in working patterns (Acaps, 2020). The United Kingdom's GDP has been forecasted to contract by 6.5% in 2020, this is a substantial deviance from the 1.4% growth recorded in 2019 (IMF, 2020). In Scotland, a stay at home order, or lockdown, began on 23rd March 2020, some control measures started a few days earlier. Controls began to lift on 29th May and gradually reduced thereafter with restrictions increased again from October (Scottish Government, 2020a).

COVID-19 outbreaks have been predicted to be a potential indirect cause of impacts on animal health and welfare through reduced availability of both labour and economic resources during the pandemic (BVA, 2020; FAO, 2020; Gortázar & de la Fuente, 2020; van Dobbenburgh & De Briyne, 2020), even in species that are not directly susceptible to COVID-19. This is due to reduced capacity to detect, manage and treat animal pathogens, although food production, as an essential activity, has been subject to fewer restrictions than other areas of the economy during the pandemic.

Scottish salmon aquaculture is a significant contributor to the UK

economy, supporting an annual turnover of £2 billion in Scotland's economy (Marsh, 2019). Aquaculture has social importance as an employer in rural regions of Scotland where few year-round employment and investment opportunities exist. These regions are predicted to exhibit less economic resilience to impacts of COVID-19 than are more urban areas (Scottish Government, 2020b). Aquaculture production depends on the health of the farmed species and this depends on good management and husbandry (COGP, 2015) which is contingent on labour, investment and on natural capital (Scottish Government, 2020b), making them potentially vulnerable to the effects of COVID-19 (BVA, 2020; FAO, 2020; Gortázar & de la Fuente, 2020; van Dobbenburgh & De Briyne, 2020). Data is collected, and published, by the Scottish Salmon Producers Organisation (SSPO) on key welfare indicators of sea lice and mortality allowing the analysis of welfare impacts associated with the COVID lockdown.

Therefore, we carried out an analysis of routes to impact and of the preliminary observations of key salmon welfare indicators up to November 2020, considering the One Health framework by identifying the links between human health under the impact of COVID-19, with animal welfare and additional environmental impacts (Rüegg, Häslar & Zinsstag, 2018). This preliminary analysis provides both a case study of COVID-19's indirect impact on farmed animal health and a specific species of importance to Scotland.

Article Summary Line: We assessed the indirect impacts on animal welfare in Scottish aquaculture during COVID-19 lockdown. Regular monitoring of key indicators continued and, did not identify negative impact on Scottish fish welfare in the short-term.

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Aquaculture industry sectors

Scottish aquaculture is dominated by Atlantic salmon (*Salmo salar*) production, however rainbow trout (*Oncorhynchus mykiss*), mussels (*Mytilus* spp.) and Pacific oysters (*Crassostrea gigas*) also account for significant sectors (Table 1). The scale and structures of production differ between sectors, in particular salmon production is handled by a small number of large multinational companies (Asche, Cojocaru, & Roth, 2018), while other species are farmed by many small companies. This has important implications for the access of different sectors to resources and markets. Small companies with fewer resources are more vulnerable to running out of funds, and may also have more difficulty getting product to markets.

Almost all the aquaculture sectors move ova or live animals between different sites; for salmon movement from freshwater to seawater is inherent in their life cycle. Movements are often over significant distances; mean distances salmon are moved in the freshwater phase and from freshwater to seawater are 81 and 201 km respectively (Wallace, Munro, Murray, Christie, & Salama, 2016), marine phase mean movements are only 10 km. A large proportion of aquaculture production is dependant on imported ova (Table 1) the movement of which along with animals requires resources and the movement of people, so could be vulnerable to disruption due to restrictions aimed at reducing the spread of COVID-19.

Production of finfish also requires that feed pellets are supplied to the farms and this uses fish meal, oil and soya that is sourced globally (Asche et al., 2018). Disruption of this chain could quickly lead to welfare issues, as could disruption in the supply of vaccines and medicines and the ability of fish health professionals such as vets and fish health inspectors to conduct visits. In contrast, shellfish, filter their own food consuming plankton, thus require much less labour and are not vulnerable to supply chains. Authorities have applied temporary relaxation of regulations to ensure medicines are available (SEPA, 2020a).

Pathways to impact of COVID-19 on aquatic animal disease management

Animal health and welfare are key issues causing problems for development of sustainable aquaculture (Jones et al., 2015; Murray & Peeler, 2005; Stien et al., 2013). We describe the routes of impact of COVID-19 on fish health and welfare assessing means by which impact occurs, the end-point indicators of that impact and sources of data to

Table 1

Structure of the Scottish aquaculture industry in 2018. Data from Munro 2020a, Munro, 2020b. FW = Freshwater, SW = seawater.

| | Atlantic salmon | Rainbow trout | Mussels | Pacific oysters |
|--------------------------------|-----------------|---------------|-----------|-----------------|
| Production (tonnes/y) | 203,881 | 7,405 | 6,699 | 369 |
| Number of production sites | 226 | 52 | 113* | 41* |
| Number of production companies | 11 | 22 | 31 | 31 |
| Ova imported | 85% | 99% | Wild spat | † |
| First sale value | £1074M | £36.2‡ | £6.2M | £1.6M |
| Feed input | Yes | Yes | No | No |
| Environment | FW then SW | FW and SW | SW | SW |

* There were 165 producing shellfish sites in 2019 but these were not separated by species in Munro, 2020b, but 69% in Scotland's Aquaculture Website (<http://aquaculture.scotland.gov.uk/>) licenced for mussels and 25% licenced for Pacific oysters.

‡ Figure not published regularly, value estimated from Marine Scotland (2016).

† Data not in Munro, 2020b, but see Murray, Munro & Matejusova, 2020, Pacific oyster spat is mostly sourced from England or the Channel Islands, there is no hatchery in Scotland.

assess that impact (Fig. 1). COVID-19 and associated management measures to protect human health lead to reduced availability of labour and economic resources for fish health and welfare which is managed under regulation and a Code of Good Practice (COGP, 2015). These potential impacts are identified as occurring through two pathways: (i) harvesting and stocking which affects disease management (Pettersen et al., 2015) and population densities which are important drivers of disease and parasites (Anderson & May, 1979; Moriarty et al., 2020; Murray & Peeler, 2005); and (ii) through surveillance and veterinary interventions for control of diseases and parasites (Oidtmann, Peeler, & Lyngstad, 2013). Regulation has been partially relaxed on both biomass limitation and sea lice to allow for COVID impacts (SEPA, 2020a, 2020b), which may lead to additional negative environmental impacts (Fig. 1).

In the medium to long term under-resourced management and poor environmental conditions can result in increases in parasites and diseases that reduce fish health and welfare, as human health and environmental effects can work synergistically to impact animal health and welfare (Rüegg et al., 2018). Mortality and parasitic sea lice prevalence are considered key indicators for fish welfare (Stien et al., 2013) that provide data on potential impacts. We consider three specific endpoints, parasitic sea lice, endemic diseases and notifiable diseases as detailed in Fig. 1.

The direct and acute impacts of COVID-19 are to reduce labour (either through restrictions or illness in the workforce), disrupt supply lines and logistics (again through restrictions or illness) and in the medium to longer term to reduce economic resources available to the production company. These are further reduced by increased costs associated with protecting employee health (e.g. PPE, testing). This may mean increased timeframes are required or a temporary reduction in resources available for protection of fish health.

Regular surveillance is vital to the timely targeting of treatments and controls for pathogens. This takes a range of forms, including daily on-site observations by staff and more occasional visits by vets or fish health professionals. Absence of the individuals, either because staff are unavailable or due to restrictions on site access has an impact on active surveillance. Reporting of data through passive surveillance is important for assessing COVID-19 impacts on animal health which can aid in strengthening policy against future impacts, and inform processes for contingency planning.

Intervention to manage pathogens can be directed with information from surveillance but requires considerable input of labour and investment, notably for sea lice management (Overton et al., 2019) which typically costs 9% of farm revenue (Abolofia, Asche, & Wilen, 2017). Options for management of infectious diseases caused by micro pathogens are more limited but can also be expensive, for example £25 M from an outbreak of ISA in the 1990s (Hastings et al., 1999).

A key activity for aquaculture production that may be impacted is harvesting. Harvesting requires both local labour and also access to logistics and markets that may be international. Delayed harvesting weakens the finances of companies, which could reduce resources and also increases the biomass of fish on the farms, increasing the risk of mortality (Moriarty et al., 2020) and higher rates of sea lice treatment (Murray & Hall, 2014). Early harvesting is also a disease management practice which can maximise potential production (Pettersen, Rich, Bang Jensen, & Aunsmo, 2015) this may not be practicable under COVID-19 restrictions.

Potential outcomes of inability to manage pathogen loads are increased sea lice infestation, increases in endemic disease losses and outbreaks of notifiable diseases. These impacts are different and measured by different data sets.

Sea lice are rated as amongst the most important pathogens for sustainable aquaculture (Jones et al., 2015) and management to reduce lice numbers is required with government intervention should loads indicate improvements in mitigation are required (Marine Scotland, 2019). Increases in lice numbers feed back to increased management

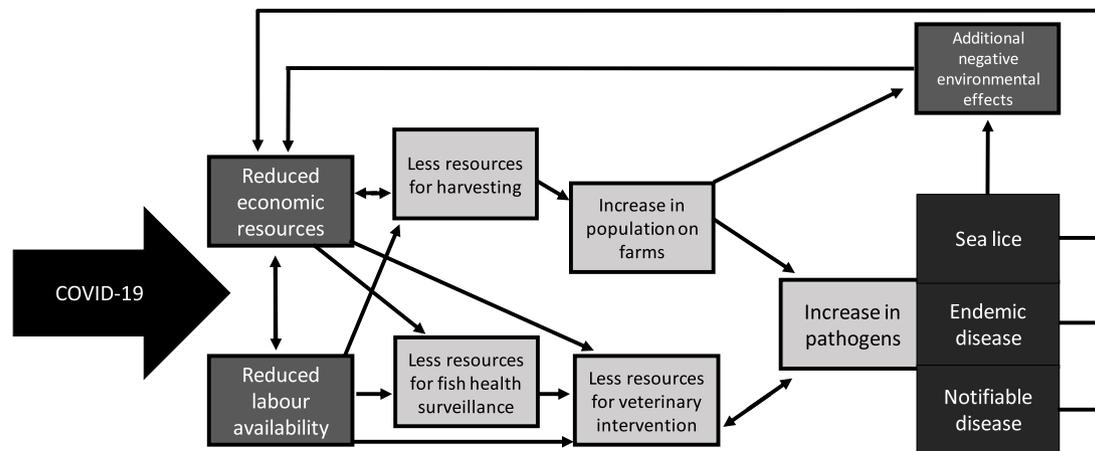


Fig. 1. Simplified schematic of potential COVID 19 pathways to impact on salmon health in aquaculture production framed within the One Health context. Here, impacts of COVID-19 restrictions to protect human health are listed in medium grey, as are the potential impacts on environment. The main focus is on the animal health impacts which may be affected by the restrictions listed. The farmed animal health/welfare related impacts which are shaded in dark grey, and processes mediating animal health impact are shaded with pale grey. Timescales of impacts are not necessarily the same, reduction in availability of labour may be acute for example whereas economic resources may be impacted in the medium to longer term.

effort with increased need for the potentially reduced labour and resources available. Sea lice can also spread to wild salmonids (Middlemas, Fryer, Tulett, & Armstrong, 2013), potentially impacting on populations (Vollset et al., 2016). Some restrictions on medicine use to control sea lice were relaxed during the COVID-19 outbreaks (SEPA, 2020a); this relaxation is temporary as medicinal residues can accumulate in sediment (Bloodworth, Baptie, Preedy, & Best, 2019).

Endemic diseases, such as Complex Gill Disorder (Noguera et al., 2019) or Pancreas Disease (Kilburn et al., 2012) cause substantial losses that are likely to increase with any potential reduction in biosecurity management (Wheatley et al. 1995), and with increased biomass (Anderson & May 1979; Moriarty et al., 2020), which has been permitted on a temporary basis (SEPA, 2020b). Any increase in mortality reduces economic resources available to the producer, and are an issue for fish welfare. However, impact on wild fish is generally likely to be moderate (Wallace et al. 2017), and since the pathogens are already endemic the system is likely to recover.

Notifiable diseases are exotic or limited in distribution, but can escape to occur large outbreaks that require considerable labour and financial resources to manage, for example Infectious Salmon Anaemia (Murray et al., 2010). However, reduced animal movements during COVID-19 could reduce the spread of outbreaks. Resources for control of such large outbreaks may be difficult to access during a pandemic, and notifiable pathogens might permanently extend their distribution if controls fail. However, notifiable diseases are still being managed, for example a Koi herpesvirus (KHV) case was dealt with by Marine Scotland's Fish Health Inspectorate (FHI), who have retained their ability to operate in spite of limitations posed by pandemic restrictions (Marine Scotland, 2020).

Preliminary assessment of key welfare indicators

Data on percentage of mortality and numbers of sea lice are published as monthly farm averages by the SSPO (<https://www.scottishsalmon.co.uk/reports>). These data were available at the time of analysis from January 2018 up to and including November 2020, thus include the entirety of the most severe lockdown period due to COVID-19 in the UK along with the preceding two years. Although this is temporally limited data, which limits statistical assessment, it is published in a timely manner (up to November 2020 at time of writing). This makes these data the best available for a preliminary analysis. Our analysis does not weight for the farms' population, so results are values per fish for the average farm, rather than national average per fish.

At a national scale there is no evidence of either excess mortality (as a percentage of total stocked fish) (Fig. 2a) or increased lice numbers (Fig. 2b) due to the impacts of COVID-19. Both metrics show minimal differences to levels seen in comparable months of 2018 and 2019, both in the median values or the variation around them. Values vary between sites but the ranges between sites are not altered from non-COVID-19 years.

For mortality in particular (and historically for sea lice (Hall & Murray, 2018)) welfare indicators are seasonal, early autumn tends to be when highest values occur, which may indicate more sensitivity to shocks during that period. However, as of November 2020 median values and the upper quartiles have remain equivalent to or below 2018 and 2019 values (Fig. 2) in all seasons. There is no indication of variation between months associated with variation in COVID-19 restrictions within 2020.

Mortality and sea lice are important indicators of welfare of farmed salmon, however a range of other factors are also significant including appetite and the physical condition of fish (Stien et al., 2013), for which we do not have data. Available data on rainbow trout and shellfish health is more limited, and published with greater time lag, making evaluation of impacts associated with COVID-19 difficult at this stage, the same is true of cleanerfish used on salmon farms to control sea lice. Indicators, both for salmon in the longer-term, and for other species, will be re-evaluated with more granularity as more data become available.

Preliminary conclusions

The COVID-19 pandemic has undoubtedly changed many aspects of our lives. The shock and disruptions have negatively impacted many businesses and industries. Here we have assessed the resilience of the aquaculture industry in terms of maintaining best practices in animal health and welfare. The initial coping responses within the sector, supported by governmental policies, have sought to maintain the sector's core functions through the period of wide-spread disruption, while protecting the most vulnerable employees and maintaining animal health and welfare. COVID-19 disruptions are against a background of climate change, which is already associated with mortality (Moriarty et al., 2020). Our preliminary evaluation is that the industry as a whole has shown resilience in its ability to withstand the various disruptions and thus far negate any negative impacts on the health and welfare of fish, that is to say we have found no gross impact on the indicators of fish health such as excess mortality and lice numbers in these early stages of the pandemic. To achieve this result, however, industry has faced

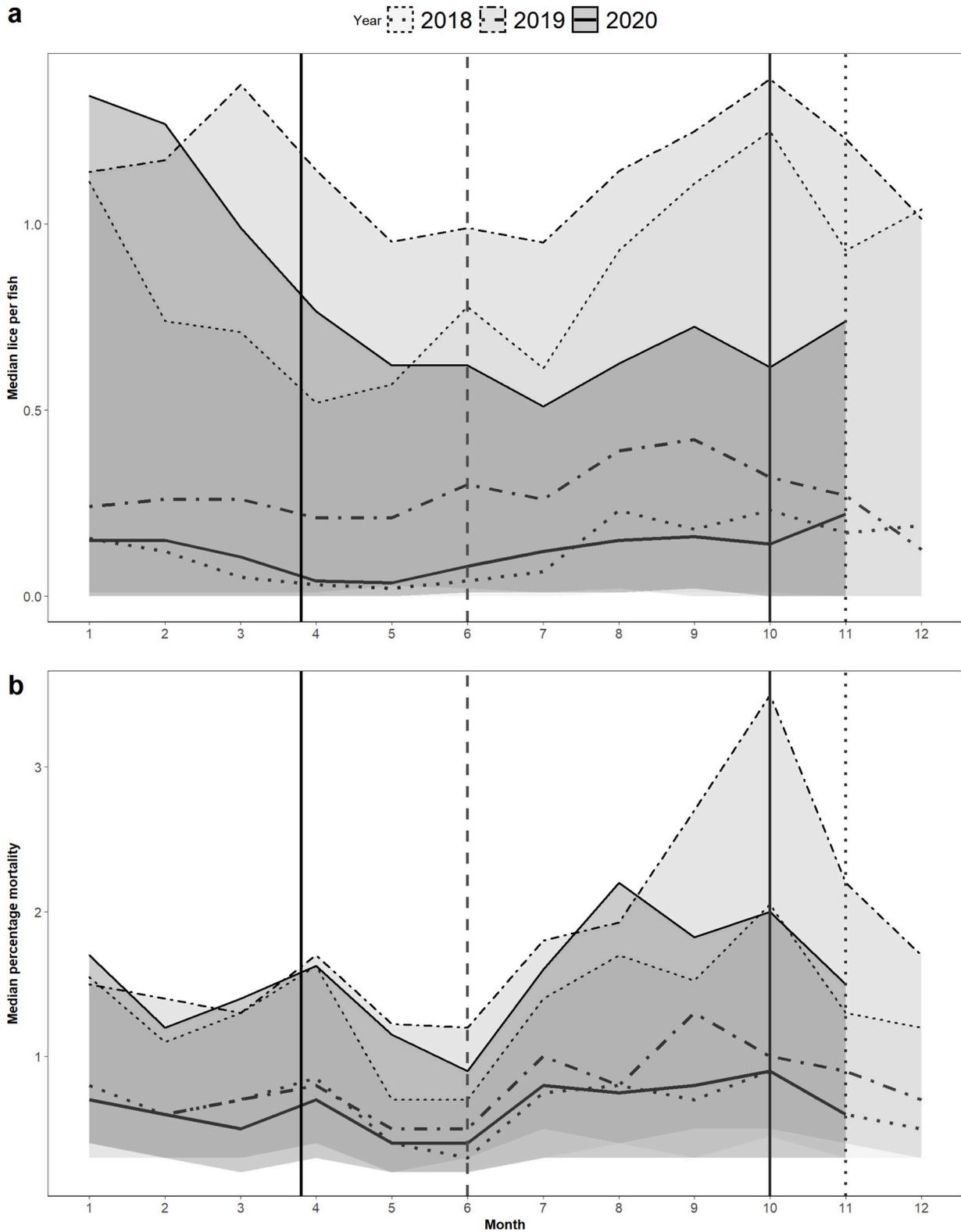


Fig. 2. (a) Median sea lice numbers with upper and lower quartiles on salmon by farm, by month for Scotland from 2018 to November 2020 (b) percentage mortality of salmon with upper and lower quartiles by farm, by month for Scotland from 2018 to November 2020. Solid vertical lines represent tightening of restrictions in March and October with the dashed line showing the beginning of easing with the move into phase 1. The dotted line represents the start of the localised 5 tier system.

additional costs and disruptions to processing and markets and these costs can increase the economic vulnerability of producers to mortality or sea lice costs, even if these are within normal ranges.

Seasonally higher levels of mortality that occurred in late Summer

and Autumn (Fig. 2a) and historically in both mortality and sea lice (Hall & Murray, 2018; Moriarty et al., 2020) could mean the system might have been more sensitive to lockdown in autumn than it was in spring.

A major outbreak of notifiable fish disease co-incident with

lockdown could have placed the system under greater stress, had this occurred. However, area management based on pre-defined areas (Murray et al., 2010), combined with reduced movements in lockdown might act as a passive limitation on a notifiable disease outbreak.

This analysis does not attempt to assess economic impacts, which clearly were very large in terms of costs of production and impacts on markets, including, but not limited to the impact on demand through the value chain. Additional data becoming available, for example on Scotland's Aquaculture Website (<http://aquaculture.scotland.gov.uk/>), will allow further and more detailed assessment of evidence for impacts at regional and farm level at a later date. Additional data on other species provided in a timely manner would allow assessment on shellfish and trout health and welfare, allowing a full and comprehensive look at the aquaculture industry.

Since data on COVID-19 impacts are available for less than one year these could be confounded by other co-incident large-scale factors affecting Scotland. However, the conclusion that there were no gross effects on salmon welfare stands. Longer-term adaptive measures, can contribute to building COVID-19-specific and generalized resilience to multiple shocks and stressors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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