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A CHARRmed life: a synthesis of scientific contributions by David Lloyd George Noakes (1942–2020)

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Abstract David Lloyd George Noakes (1942–2020) was a remarkable man. He was a friend, mentor, professor, editor, and writer. Herein, his peer-reviewed and edited publications are compiled and synthesized to demonstrate his academic contributions. David generated more than 213 publications including nine books, 29 book sections, and 175 peer-reviewed articles between 1973 and 2021. His research was focused in three main themes: (1) behaviour, ecology, and evolution of fishes; (2) behaviour as it influences fish populations; and (3) native salmonine conservation. Within these themes, 38 species in 16 families and three classes were studied, Salmonidae being the most prevalent taxon representing nearly 60% of published articles. He cared deeply about people, history, and tradition; he led or contributed to 12 tributes to the foremothers and fathers of fish biology. David was collaborative. He was remarkable at facilitating connections and establishing strong and lasting relationships. His network consisted of at least 262 unique co-authors spanning 17 countries and representing 110 unique partner institutions. This bibliographic synthesis is intended to form the basis for the many detailed investigations of notable achievements, advancement of fields, and societal impacts within this issue that together honour the loss of a giant in our field.

Keywords Behaviour · Conservation · Ecology · Ethology · Life history · Salmonidae

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Introduction

How do we adequately capture and celebrate the scientific achievements of our mentors, colleagues, and peers to honour their legacy? Measuring and interpreting impact in the natural sciences remains a challenge (Sinatra et al. 2016). While simple indices, such as H-index, provide a measure of academic output that may approximate impact (Pauly and Stergiou 2005), they do not begin to capture broader socio-economic effects of a scientific career or the personal achievements and influence of a scientist (see https://sfdora.org/). Citation analysis largely fails to capture career contributions to the economy, environment, culture, quality of life, human health, and society (Penfield et al. 2014). This shortfall permeates through the academic reward system. For instance, a recent survey of 126 Flemish researchers identified that research assessment indicators related to openness, transparency, quality, and innovation were perceived as highly important in advancing science, but largely overlooked in faculty evaluations and career advancement decisions (Aubert Bonn and Pinxten 2021). Moreover, the influence of our mentors

on their peer and student networks extends broadly, having far-reaching implications that are difficult to identify and assess qualitatively and even more difficult to assess quantitatively. The field of bibliometrics is rapidly advancing our ability to better capture the sphere of influence of a scientist and their contributions beyond simple indices. Herein, I use bibliometric tools to synthesize the scientific contributions of the late David Lloyd George Noakes (1942–2020) based on a compiled Endnote™ library of his publications (library available upon request). David was scientifically productive, but his legacy far exceeds simple academic standards in myriad ways; his career provides a shining example of great science and the life of a great scientist.

The compiled bibliography is not likely complete, but it provides a large enough sample to draw meaningful inferences about David's scientific contributions. I sincerely apologize for any omissions as they were unintentional. While a simple synthesis of academic achievements falls short of demonstrating the immense impact of this remarkable man, it should provide readers with a sense for the scope and scale of David's scientific contributions and provide a glimpse of the diverse global network he developed and nurtured over the course of his career. This bibliographic synthesis is intended to form the basis for the many detailed investigations of notable achievement, advancement of fields, and societal impact within this volume that together may honour the loss of a giant in our field—David Lloyd George Noakes (1942–2020).

The professional career of Dr. D.L.G. Noakes

David Noakes was a scholar and educator. In 1965, he earned a B.Sc. (Honours) in Biology, and in 1966, an M.Sc. in Zoology from the University of Western Ontario. In 1971, he earned a Ph.D. in Zoology from University of California, Berkeley. After a brief stint as demonstrator in the Zoology Department at the University of Edinburgh (1970–1972), he accepted a position at University of Guelph, Ontario where he spent 33 years (1972–2005). During his time at Guelph, he served as Assistant, Associate, and Full Professor, Acting Chair of the Zoology Department (1989–1990), and Director of the Axelrod Institute of Ichthyology (1990–1996; 2000–2002). In 2005, he accepted the position of Full Professor at Oregon State University in the Fisheries and Wildlife Department, serving as Director of the Oregon Hatchery Research Center (OHRC) where he remained until his passing in 2020. David also served as a visiting professor at 11 institutions in Canada, China, England, Germany, Iceland, Japan, Thailand, and the USA.

Bibliographic overview

David Noakes was an editor. He served as Editor of the Fish & Fisheries Monograph Series (Springer; 1999–2020), Editor-in-Chief of Environmental Biology of Fishes (Springer; 2001–2020); Co-Editor of Fundamental Ecology monograph series (Springer; 2005–2020); and Editor of Guelph Ichthyology Reviews (1990–2005). He has also served as Advisory Editor for Canadian Journal of Fisheries and Aquatic Sciences (1995–1997) and Associate Editor for Transactions of the American Fisheries Society (1997–1998). Editorial service is part of the "invisible labor" of academia and often unrecognized or undervalued in academic reward structures, even though it prominently contributes to advancing fields, steering future research directions, and providing a primary teaching resource.

David was a prolific writer. He produced more than 213 publications including nine books, 29 book sections, and 175 peer-reviewed articles between 1973 and 2021 (average ~ 4.5 publications per year; Table 1). According to his 2010 curriculum vitae, he also published 15 non-peer-reviewed reports and 14 book reviews between 1969 and 2010 (not included in Table 1). I was unable to collect accurate records of non-peer-reviewed publications for the last decade or so of his career, but these certainly included annual reports of the OHRC and other valuable contributions. Several articles he co-authored and a book—The behavior, ecology and evolution of cichlid fishes; edited by Maria E. Abate and David L.G. Noakes (2021; not included in Table 1 as it was published after compiling the data for the current article)—were published posthumously, and more contributions may be forthcoming. David was the sole author of 34 (~ 16%) and lead author of 22 (~ 10%) articles. David used publishing as a means to mentor and advance the careers of junior members of his network, often offering them lead authorship as opposed to taking credit

Table 1 Bibliography of publications by David L.G. Noakes between 1972 and 2021

Publication number	Reference
1	Albins MA, Evans A, Ismail GB, Neilsen B, Pusack T, Schemmel E, Smith W, Stoike S, Li HW, Noakes DLG (2011) Can humans coexist with fishes? Environ Biol Fishes 96:1301–1313
2	Armstrong ER, Noakes DLG (1977a) Precocial testicular maturation in the mourning dove, *Zenaida macroura.* Can J Zool 55:2065–2066
3	Armstrong ER, Noakes DLG (1977b) Albino mourning dove sightings in Ontario. Auk 94:158–158
4	Armstrong ER, Noakes DLG (1981) Food habits of morning doves in southern Ontario. J Wildl Manag 45:222–227
5	Armstrong ER, Noakes DLG (1983) Wintering biology of morning doves, *Zenaida macroura* in Ontario. Can Field-Nat 97:434–438
6	Auld HL, Noakes DLG, Banks MA (2019) Advancing mate choice studies in salmonids. Rev Fish Biol Fish 29:249–276
7	Auld HL, Jacobson DP, Rhodes AC, Banks MA (2021) Differences in mate pairings of hatchery- and natural-origin coho salmon inferred from offspring genotypes. Integr Org Biol 3:1–10
8	Balon EK, Bruton MN, Noakes DLG (1994) Prelude to the anthology in honour of women ichthyologists. Environ Biol Fishes 41:7–8
9	Balon EK, Bruton MN, Noakes DLG (eds) (2012) Women in ichthyology: an anthology in honour of ET, Ro and Genie. Springer Science + Business Media, B.V., Dordrecht
10	Beamish FWH, Jebbink J, Rossiter A, Noakes DLG (1996) Growth strategy of juvenile lake sturgeon (*Acipenser fulvescens*) in a northern river. Can J Fish Aquat Sci 53:481–489
11	Beamish FWH, Noakes DLG, Rossiter A (1998) Feeding ecology of juvenile lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Can Field-Nat 112:459–468
12	Beamish RJ, Noakes DJ, Noakes DLG, Beamish FWH (2003) In Memoriam/Nécrologie: William Edwin Ricker, OC, FRSC, LLD, DSc. Can J Fish Aquat Sci 60:iii-v
13	Bernard AM, Taylor E, Ferguson MM, Noakes DLG, Morrison BJ, Wilson CC (2009) How different is different? Defining management and conservation units for a problematic exploited species. Can J Fish Aquat Sci 66:1617–1630
14	Billman EJ, Whitman LD, Schroeder RK, Sharpe CS, Noakes DLG, Schreck CB (2014) Body morphology differs in wild juvenile Chinook salmon *Oncorhynchus tshawytscha* that express different migratory phenotypes in the Willamette River, Oregon, U.S.A. J Fish Biol 85:1097–1110
15	Biro PA, Ridgway MS, Noakes DLG (1997) The central-place territorial model does not apply to space-use by juvenile brook charr *Salvelinus fontinalis* in lakes. J Anim Ecol 66:837–845
16	Blackie CT, Weese DJ, Noakes DLG (2003) Evidence for resources polymorphism in the lake charr (*Salvelinus namaycush*) of Great Bear Lake, Northwest Territories, Canada. Ecoscience 10:509–514
17	Brown DM, Noakes DLG (1974) Habituation and recovery of aggressive display in paradise fish (*Macropodus opercularis* (L.)). Behav Biol 10:519–525
18	Carey WE, Noakes DLG (1981) Development of photobehavioral response in young rainbow trout, *Salmo gairdneri* Richardson. J Fish Biol 19:285–296
19	Chiasson WB, Noakes DLG, Beamish FWH (1997) Habitat, benthic prey, and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Can J Fish Aquat Sci 54:2866–2871
20	Church MR, Ebersole JL, Rensmeyer KM, Couture RB, Barrows FT, Noakes DLG (2009) Mucus: a new tissue fraction for rapid determination of fish diet switching using stable isotope analysis. Can J Fish Aquat Sci 66:1–5
21	Clemens BJ, Beamish RJ, Coates KC, Docker MF, Dunham JB, Gray AE, Hess JE, Jolley JC, Lampman RT, Mcllraith BJ, Moser ML, Murauskas JG, Noakes DLG, Schaller HA, Schreck CB, Starcevich SJ, Streif B, van de Wetering SJ, Wade J, Weitkamp LA, Wyss LA (2017) Conservation challenges and research needs for Pacific Lamprey in the Columbia River basin. Fisheries 42:268–280
22	Cogliati KM, Unrein JR, Stewart HA, Schreck CB, Noakes DLG (2017) Egg size and emergence timing affect morphology and behavior in juvenile Chinook Salmon, *Oncorhynchus tshawytscha.* Ecol Evol 8:778–789
23	Cogliati KM, Herron CL, Noakes DLG, Schreck CB (2019a) Altered hatchery rearing: producing wild fish phenotypes for research with ESA listed species. Aquaculture

Table 1 (continued)

Publication number	Reference
24	Cogliati KM, Herron CL, Noakes DLG, Schreck CB (2019b) Reduced stress response in juvenile Chinook Salmon reared with structure. Aquaculture 504:96–101
25	Cogliati KM, Unrein JR, Schreck CB, Noakes DLG (2019c) Rearing environment affects spatial learning in juvenile Chinook salmon *Oncorhynchus tshawytscha.* J Fish Biol 95:870–880
26	Cogliati KM, Unrein JR, Sealey WM, Barrows FT, Hakanson O, Chitwood R, Noakes DLG, Schreck CB (2019d) Low-lipid diets fed at reduced ration: effects on growth, body composition, and survival of juvenile Chinook salmon. J Fish Wildl Manag 10:500–508
27	Cole KS, Noakes DLG (1980) Development of early social behaviour of rainbow trout *Salmo gairdneri* (Pisces, Salmonidae). Behav Process 5:97–112
28	Cole KS, Noakes DLG (1997) Gonadal development and sexual allocation in mangrove killifish, *Rivulus marmoratus* (Pisces: Atherinomorpha). Copeia 1997:596–600
29	Cole KS, Noakes DLG, Thompson N, Blouin M, Morrison B, Couture RB, O'Neil J, Schreck CB (2021) Effects of temperature on sexual development in steelhead, *Oncorhynchus mykiss.* Environ Biol Fishes 104:229–238
30	Curry RA, Gehrels J, Noakes DLG, Swainson R (1994) Effects of river flow fluctuations on groundwater discharge through brook trout, *Salvelinus fontinalis*, spawning and incubation habitats. Hydrobiologia 277:121–134
31	Curry RA, Noakes DLG, Morgan GE (1995) Groundwater and the incubation and emergence of brook trout (*Salvelinus fontinalis*). Can J Fish Aquat Sci 52:1741–1749
32	Curry RA, Brady C, Noakes DLG, Danzmann RG (1997) Use of small streams by young brook trout spawned in a lake. Trans Am Fish Soc 126:77–83
33	Curry RA, Noakes DLG (1995) Groundwater and the selection of spawning sites by brook trout (*Salvelinus fontinalis*). J Gt Lakes Res 52:1733–1740
34	Danzmann RG, Ferguson MM, Skúlason S, Snorrason SS, Noakes DLG (1991) Mitochondrial DNA diversity among four sympatric morphs of Arctic charr, *Salvelinus alpinus* L., from Thingvallavatn, Iceland. J Fish Biol 39:649–659
35	Danzmann RG, Ferguson MM, Noakes DLG (1993) Genetics of fish behaviour. In: Pitcher TJ (ed) The behaviour of teleost fishes, 2nd edn. Croom-Helm, London, pp 3–30
36	De Kerckhove D, McLaughlin RL, Noakes DLG (2006) Ecological mechanisms favouring behavioural diversification in the absence of morphological diversification: a theoretical examination using brook charr (*Salvelinus fontinalis*). J Anim Ecol 75:506–517
37	Dittman AH, Pearsons TN, May D, Couture RB, Noakes DLG (2015) Imprinting of hatchery-reared salmon to targeted spawning locations: a new embryonic imprinting paradigm for hatchery programs. Fisheries 40:114–123
38	Dodd HR, Hayes DB, Baylis JR, Carl LM, Goldstein JD, McLaughlin RL, Noakes DLG, Porto LM, Jones ML (2003) Low-head sea lamprey barrier effects on stream habitat and fish communities in the Great Lakes basin. J Gt Lakes Res 29 (Supplement 1):386–402
39	Ferguson MM, Noakes DLG, Danzmann RG (1981) Morphological and biochemical systematics of chubs, *Nocomis biguttatus* and *N. micropogon* (Pisces, Cyprinidae), in southern Ontario. Can J Zool 59:771–775
40	Ferguson MM, Noakes DLG, Romani D (1983) Restricted behavioural plasticity of juvenile lake charr, *Salvelinus namaycush.* Environ Biol Fishes 8:151–156
41	Ferguson MM, Noakes DLG, Skulason S, Snorrason SS (1990) Life-history styles and somatic allocation in iteroparous Arctic charr and semelparous pink salmon. Environ Biol Fishes 28:267–272
42	Ferguson MM, Noakes DLG (1981) Social grouping and genetic variation in common shiners, *Notropis cornutus* (Pisces, Cyprinidae). Environ Biol Fishes 6:357–360
43	Ferguson MM, Noakes DLG (1982) Genetics of social behavior in charrs (*Salvelinus species*). Anim Behav 30:128–134
44	Ferguson MM, Noakes DLG (1983a) Behavioural plasticity of lake charr (*Salvelinus namaycush*) x brook charr (*S. fontinalis*) F1 hybrids in response to varying social envrionment. Behav Process 8:147–156
45	Ferguson MM, Noakes DLG (1983b) Movers and stayers: genetic analysis of mobility and positioning in hybrids of lake charr, *Salvelinus namaycush*, and brook charr, *S. fontinalis* (Pisces, Salmonidae). Behav Genet 13:213–222

Table 1 (continued)

Publication number	Reference
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48	Gao Y, Bargmann GG, Brand U, Noakes DLG (2005) Stable isotopic and trace elemental compositions of otoliths and the stock structure of Pacific cod, *Gadus macrocephalus.* Environ Biol Fishes 74:335–348
49	Gao Y, Conrad R, Bean D, Noakes DLG (2012) Statistical analysis on otolith data of anadromous fishes. Environ Biol Fishes 96:799–810
50	Gao Y, Noakes DLG (2012) Chemical signatures of otoliths and application in fisheries. Environ Biol Fishes 95:415–418
51	Grant JWA, Noakes DLG, Jonas KM (1989) Spatial distribution of defence and foraging in young-off-the-year brook charr, *Salvelinus fontinalis.* J Anim Ecol 58:773–784
52	Grant JWA, Noakes DLG (1986) A test of a size-selective predation model with juvenile brook charr, *Salvelinus fontinalis.* J Fish Biol 29 (Supplement A):15–23
53	Grant JWA, Noakes DLG (1987a) Escape behaviour and use of cover by young-of-the-year brook trout, *Salvelinus fontinalis.* Can J Fish Aquat Sci 44:1390–1396
54	Grant JWA, Noakes DLG (1987b) Movers and stayers: foraging tactics of young-of-the-year brook charr, *Salvelinus fontinalis.* J Anim Ecol 56:1001–1013
55	Grant JWA, Noakes DLG (1987c) A simple model of optimal territory size for drift-feeding fish. Can J Zool 65:270–276
56	Grant JWA, Noakes DLG (1988) Aggressiveness and foraging mode of young-of-the-year brook charr, *Salvelinus fontinalis* (Pisces, Salmonidae). Behav Ecol Sociobiol 22:435–445
57	Green RF, Noakes DLG (1995) Is a little bit of sex as good as a lot? J Theor Biol 174:87–96
58	Griffiths RW, Newlands NK, Noakes DLG, Beamish FWH (2004) Northern pike (*Esox lucius*) growth and mortality in a northern Ontario river compared with that in lakes: influence of flow. Ecol Freshw Fish 13:136–144
59	Grush J, Noakes DLG, Moccia RD (2004) The efficacy of clove oil as an anesthetic for the zebrafish, *Danio rerio* (Hamilton). Zebrafish 1:46–53
60	Gunn JM, Noakes DLG, Westlake GF (1987) Behavioural responses of lake charr (*Salvelinus namaycush*) embryos to simulated acidic runoff conditions. Can J Zool 65:2786–2792
61	Gunn JM, Noakes DLG (1986) Avoidance of low pH and elevated AI concentrations by brook charr (*Salvelinus fontinalis*) alevins in laboratory tests. Water, Air and Soil Pollution 30:497–503
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63	Hayes DB, Baylis JR, Carl LM, Dodd HR, Goldstein JD, McLaughlin RL, Noakes DLG, Porto LM (2003) Biological effect of low-head sea lamprey barriers: designs for extensive surveys and the value of incorporating intensive process-oriented research. J Gt Lakes Res 29 (Supplement 1):373–385
64	Hixon MA, Gregory SV, Robinson WD, Baker CS, Batchelder HP, Epps C, Garcia TS, Haig SM, Letelier RM, Lytle DA, Menge BA, Miller JC, Noakes DLG, Peterson WT, Rice JM, Rumrill SS, Schreck CB, Suryan RM, Sytsma MD, White AE (2010) Case study 7: Oregon's fish and wildlife in a changing climate. In: Dello KD, Mote PW (eds) The Oregon climate change assessment report. Oregon Climate Change Research Institute, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, p 93
65	Holloway AC, Keene JL, Noakes DLG, Moccia RD (2004) Effects of clove oil and MS-222 on blood hormone profiles in rainbow trout *Oncorhynchus mykiss*, Walbaum. Aquac Res 35:1025–1030
66	Imre I, McLaughlin RL, Noakes DLG (2001) Temporal persistence of resource polymorphism in brook charr, *Salvelinus fontinalis.* Environ Biol Fishes 60:393–399
67	Imre I, McLaughlin RL, Noakes DLG (2002) Phenotypic plasticity in brook charr: changes in caudal fin induced by water flow. J Fish Biol 61:1171–1181
68	Ismail GB, Sampson DB, Noakes DLG (2014) The status of Lake Lanao endemic cyprinids (*Puntius* species) and their conservation. Environ Biol Fishes 97:425–434

Table 1 (continued)

Publication number	Reference
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71	Keene JL, Noakes DLG, Moccia RD, Soto CG (1998) The efficacy of clove oil as an anaesthetic for rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquac Res 29:89–101
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76	Kristjánsson BK, Skúlason S, Noakes DLG (2002b) Morphological segregation of Icelandic threespine stickleback (*Gasterosteus aculeatus* L). Biol J Linn Soc 76:247–257
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82	Linton ED, Jónsson B, Noakes DLG (2006) Effects of water temperature on the swimming and climbing behaviour of glass eels, *Anguilla* spp. Environ Biol Fishes 78:189–192
83	Mackereth RW, Noakes DLG, Ridgway MS (1999) Size-based variation in somatic energy reserves and parental expenditure by male smallmouth bass, *Micropterus dolomieu.* Environ Biol Fishes 56:263–275
84	MacPherson A, Holmes JA, Muir AM, Noakes DLG (2010) Assessing feeding competition between lake whitefish *Coregonus clupeaformis* and round whitefish *Prosopium cylindraceum.* Current Zoology 56:109–117
85	Mahon R, Balon EK, Noakes DLG (1979) Distribution, community structure and production of fishes in the upper Speed River, Ontario: a preimpoundment study. Environ Biol Fishes 4:219–244
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Table 1 (continued)

Publication number	Reference
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91	McLaughlin RL, Grant JWA, Noakes DLG (2000) Living with failure: the prey capture success of young brook charr in streams. Ecol Freshw Fish 9:81–89
92	McLaughlin RL, Carl LM, Middel T, Ross M, Noakes DLG, Hayes DB, Baylis JR (2001) Potentials and pitfalls of integrating data from diverse sources: lessons from a historical database for Great Lakes stream fishes. Fisheries 26:14–23
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94	McLaughlin RL, Noakes DLG (1998) Going against the flow: an examination of the propulsive movements made by young brook trout in streams. Can J Fish Aquat Sci 55:853–860
95	McNicol RE, Noakes DLG (1979) Caudal fin branding fish for individual recognition in behavior studies. Behav Res Methods Instrum 11:95–97
96	McNicol RE, Noakes DLG (1981) Territories and territorial defense in juvenile brook charr, *Salvelinus fontinalis* (Pisces: Salmonidae). Can J Zool 59:22–28
97	McNicol RE, Noakes DLG (1984) Environmental influences on territoriality of juvenile brook charr, *Salvelinus fontinalis*, in a stream environment. Environ Biol Fishes 10:29–42
98	McPhee MV, Noakes DLG, Allendorf FW (2012) Developmental rate: a unifying mechanism for sympatric divergence in postglacial fishes? Curr Zool 32:716–719
99	Minamimoto M, Sakakura Y, Soyano K, Hagiwara A, Noakes DLG (2003) Reproductive physiology in the self-fertilizing mangrove killifish, *Rivulus marmoratus.* EAS Spec Pub 33:264–265
100	Ming FW, Noakes DLG (1984) Spawning site selection and competition in minnows (*Pimephales notatus* and *Pimephales promelas*) (PISCES, CYPRINIDAE). Behav Biol 9:227–234
101	Miura G, Munakata A, Yada T, Schreck CB, Noakes DLG, Matsuda H (2013) Effect of short-term decrease in water temperature on body temperature and involvement of testosterone in steelhead and rainbow trout, *Oncorhynchus mykiss.* Comp Biochem Physiol Part A 166:112–118
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103	Munakata A, Ogihara E, Schreck CB, Noakes DLG (2017) Effects of short term acclimation in cool and warm water and influent water temperatures on temperature selection behavior in juvenile steelhead trout, *Oncorhynchus mykiss.* Aquaculture 467:219–224
104	Naisbett-Jones LC, Putman NF, Scanlan MM, Noakes DLG, Lohmann KJ (2020) Magnetoreception in fishes: the effect of magnetic pulses on orientation of juvenile Pacific salmon. J Exp Biol 223:1–6
105	Neave FB, Mandrak NE, Docker MF, Noakes DLG (2006) Effects of preservation on pigmentation and length measurements in larval lampreys. J Fish Biol 68:991–1001
106	Neave FB, Mandrak NE, Docker MF, Noakes DL (2007) An attempt to differentiate sympatric *Ichthyomyzon* ammocoetes using meristic, morphological, pigmentation, and gonad analyses. Can J Zool 85:549–560
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109	Noakes DLG (1976) Parental behavior and some histological observations of scales in *Cichlasoma citrinellum* (Pisces, Cichlidae). In: Thorson TB (ed) Investigations of the Ichthyofauna of Nicaraguan Lakes. University of Nebraska Press, Lincoln, pp 423–458
110	Noakes DLG (1978a) Early behaviour in fishes. Environ Biol Fishes 3:321–326
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Table 1 (continued)

Publication number	Reference
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113	Noakes DLG (1979) Parent-touching behavior by young fishes: incidence, function and causation. Environ Biol Fishes 4:389–400
114	Noakes DLG (1980a) Some histological observations on the skin of charrs. In: Balon EK (ed) Samonid fishes of the genus *Salvelinus*. Dr. W. Junk Publishers, The Hague, pp 423–433
115	Noakes DLG (1980b) Social behavior in young charrs. In: Balon EK (ed) Charrs Salmonid fishes of the genus *Salvelinus*, vol 1. Perspectives in Vertebrate Science. Dr. W. Junk bv Publishers, The Hague, pp 683–701
116	Noakes DLG (1981) Comparative aspects of behavioural development: a philosophy from fishes. In: Immelmann K, Barlow GW, Petrinovitch L, Main M (eds) Early development of behaviour. Cambridge University Press, Cambridge, England, pp 491–508
117	Noakes DLG (1982a) Effect of chemical signals in *Betta splendens.* Rev Can Biol Exp 41:217–219
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119	Noakes DLG, Lindquist DG, Helfman GS, Ward JA (eds) (1983a) Predators and prey in fishes. Proceedings of the 3rd Biennial Conference on the Ethology and Behavioral Ecology of Fishes 19–22 May 1981, held at Normal, IL USA vol 2. Developments in Environ Biol Fishes. Springer, Dordrecht, pp. 5–6
120	Noakes DLG, Lindquist DG, Helfman GS, Ward JA (1983b) Predators and prey in fishes. In: Noakes DLG, Lindquist DG, Helfman GS, Ward JA (eds) Predators and prey in fishes, vol 2. Developments in Environ Biol Fishes. Springer, Dordrecht, pp 5–6
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131	Noakes DLG (1993b) Ethelwyn Trewavas—a charmed life. Environ Biol Fishes 38:295–298
132	Noakes DLG (1994a) The life and work of Ethelwynn Trewavas: beyond the focus on tilapiine cichlids. Environ Biol Fishes 41:33–49
133	Noakes DLG (1994b) Lifetime list of publications by Ethelwynn Trewavas. Environ Biol Fishes 41:51–54
134	Noakes DLG (1994c) An interview with Ethelwynn Trewavas. Environ Biol Fishes 41:63–65

Table 1 (continued)

Publication number	Reference
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136	Noakes DLG, Ferguson MM, Ashford B, Stott W (1995) Size and shape variation in Laurentian Great Lakes pink salmon. Am Fish Soc Symp 17:185–194
137	Noakes DLG (1998) A new perspective on lakes: Kawanabe's latest acheivements. Environ Biol Fishes 52:391–394
138	Noakes DLG, Beamish FWH, Rossiter A (1999) Conservation implications of behaviour and growth of the lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Environ Biol Fishes 55:135–144
139	Noakes DLG (2003) Changes and continuity. Environ Biol Fishes 66:1
140	Noakes DLG (2006a) Bill Ricker: a tribute. In: Noakes DLG (ed) Bill Ricker: an appreciation. Developments in Environ Biol Fishes, vol 24. Springer, Dordrecht, The Netherlands, pp 1–5
141	Noakes DLG (ed) (2006b) Bill Ricker: an appreciation vol 75. Environ Biol Fishes 24. Springer, Dordrecht
142	Noakes DLG (2008a) 2006 International Charr Symposium, Reykjavik, Iceland. Environ Biol Fishes 83:1–5
143	Noakes DLG (2008b) Charr truth: sympatric differentiation in *Salvelinus* species. Environ Biol Fishes 83:7–15
144	Noakes DLG (2010) Introducing China. In: Noakes DLG, Romero A, Zhao Y, Zhou Y (eds) Chinese fishes. Developments in Environ Biol Fishes 28. Springer, Dordrecht, pp 1–9
145	Noakes DLG, Romero A, Zhao Y, Zhou Y (eds) (2010) Chinese fishes. Environ Biol Fishes 28. Springer, Dordrecht
146	Noakes DLG (2011) On our origins. Environ Biol Fishes 91:1–5
147	Noakes DLG (2014) Behavior and genetics of salmon. In: Woo PTK, Noakes DLG (eds) Salmon: biology, ecological impacts and economic importance. Fish, Fishing and Fisheries. Nova Science Publishers, New York, pp 195–222
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150	Noakes DLG, Barlow GW (1973a) Cross-fostering and parent–offspring responses in *Cichlasoma citrinellum* (Pisces, Cichlidae). Z Tierpsychol 33:147–152
151	Noakes DLG, Barlow GW (1973b) Ontogeny of parent-contacting in young *Cichlasoma citrinellum* (Pisces, Cichlidae). Behaviour 46:221–255
152	Noakes DLG, Baylis JR (1990) Behavior. In: Schreck CB, Moyle PB (eds) Methods for fish biology. American Fisheries Society, Bethesda, Maryland, pp 555–583
153	Noakes DLG, Bouvier LD (2013) Threatened fishes of the world: the end of a series. Environ Biol Fishes 96:1135–1149
154	Noakes DLG, Corrarino C (2010) The Oregon Hatchery Research Center: an experimental laboratory in a natural setting. J World Aquacult Soc 41:33–37
155	Noakes DLG, Curry RA (1995) Lessons to be learned from attempts to restore *Salvelinus* species other than *S. namaycush*: a review of reproductive behavior. J Gt Lakes Res 21 (Supplement 1):54–64
156	Noakes DLG, Godin JJ (1988) 5 Ontogeny of behavior and concurrent developmental changes in sensory systems in teleost fishes. In: Hoar WS, Randall DJ (eds) Fish Physiol, Volume 11, Part B, pp 345–395
157	Noakes DLG, Grant JWA (1986) Behavioral ecology and production of riverine fishes. Pol Arch Hydrobiol 33:249–262
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Table 1 (continued)

Publication number	Reference
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165	Nunan CP, Noakes DLG (1985b) Response of rainbow trout (*Salmo gairdneri*) embryos to current flow in simulated substrates. Can J Zool 63:1813–1815
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172	Piccolo J, Noakes DLG, Hayes JW (2014) Preface to the special drift foraging issue of Environmental Biology of Fishes. Environ Biol Fishes 97:449–451
173	Pollock AMM, Kamran M, Dittman AH, Johnson MA, Noakes DLG (2020) Within-river straying: sex and size influence recovery location of hatchery Chinook salmon (*Oncorhynchus tshawytscha*). Can J Fish Aquat Sci 77:226–235
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179	Putman NF, Jenkins ES, Michielsens CG, Noakes DLG (2014a) Geomagnetic imprinting predicts spatio-temporal variation in homing migration of pink and sockeye salmon. J R Soc Interface 2014 11, 20,140,542
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182	Putman NF, Scanlan MM, Pollock AM, O'Neil JP, Couture RB, Stoner JS, Quinn TP, Lohmann KJ, Noakes DLG (2018) Geomagnetic field influences upward movement of young Chinook salmon emerging from nests. Biol Lett 14:20,170,752

Table 1 (continued)

Publication number	Reference
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185	Rand PS, Berejikian BA, Pearsons TN, Noakes DLG (eds) (2013) Ecological interactions of hatchery and wild salmon. Developments in Environ Biol Fishes, vol 29. Springer, Netherlands
186	Riley SC, Hansen MJ, Krueger CC, Noakes DLG, Muir AM (2021) Introduction. The lake charr: biology, ecology, distribution, and management. In: Muir AM, Hansen MJ, Riley SC, Krueger CC (eds) The lake charr *Salvelinus namaycush*: biology, ecology, distribution, and management, vol 39. Springer Nature, Switzerland, pp 1–12
187	Romer JD, Leblanc CA, Clements S, Ferguson JA, Kent ML, Noakes D, Schreck CB (2012) Survival and behavior of juvenile steelhead trout (*Oncorhynchus mykiss*) in two estuaries in Oregon, USA. Environ Biol Fishes 96:849–863
188	Rooney N, McCann KS, Noakes DLG (eds) (2007) From energetics to ecosystems: the dynamics and structure of ecological systems, vol 1. The Peter Yodzis Fundamental Ecology Series. Springer, Dordrecht, The Netherlands
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191	Sakakura Y, Noakes DLG (2000) Age, growth, and sexual development in the self-fertilizing hermaphroditic fish *Rivulus marmoratus.* Environ Biol Fishes 59:309–317
192	Scanlan MM, Putman NF, Pollock AM, Noakes DLG (2018) Magnetic map in nonanadromous Atlantic salmon. Proc Natl Acad Sci USA 115:10,995–10,999
193	Scott RJ, Ridgway MS, Noakes DLG (1997) The nest range of smallmouth bass (*Micropterus dolomieu*): parental care after swim-up. Can J Zool 75:2058–2062
194	Scott RJ, Noakes DLG, Beamish FWH, Carl LM (2003) Chinook salmon impede Atlantic salmon conservation in Lake Ontario. Ecol Freshw Fish 12:66–73
195	Scott RJ, Judge KA, Ramster K, Noakes DLG, Beamish FWH (2005a) Interactions between naturalised exotic salmonids and reintroduced Atlantic salmon in a Lake Ontario tributary. Ecol Freshw Fish 14:402–405
196	Scott RJ, Kosick R, Clement M, Noakes DLG, Beamish FWH (2005b) Nest site selection and spawning by captive bred Atlantic salmon, *Salmo salar*, in a natural stream. Environ Biol Fishes 74:309–321
197	Scott RJ, Poos MS, Noakes DLG, Beamish FWH (2005c) Effects of exotic salmonids on juvenile Atlantic salmon behaviour. Ecol Freshw Fish 14:283–288
198	Self KE, Schreck CB, Cogliati KM, Billman EJ, Noakes DLG (2018a) Egg size and growth in steelhead *Oncorhynchus mykiss.* J Fish Biol 93:465–468
199	Self KE, Schreck CB, Cogliati KM, Billman EJ, Noakes DLG (2018b) The effect of rearing structures on behaviour and movement of juvenile steelhead *Oncorhynchus mykiss.* J Fish Biol 93:449–454
200	Skúlason S, Noakes DLG, Snorrason SS (1989a) Ontogeny of trophic morphology in four sympatric morphs of Arctic charr *Salvelinus alpinus* in Thingvallavatn, Iceland. Biol J Linn Soc 38:281–301
201	Skúlason S, Snorrason SS, Noakes DLG, Ferguson MM, Malmquist HJ (1989b) Segregation in spawning and early life history among polymorphic Arctic charr, *Salvelinus alpinus*, in Thingvallavatn, Iceland. J Fish Biol 35 (Supplement A):225–232
202	Skúlason S, Snorrason SS, Ota D, Noakes DLG (1993) Genetically based differences in foraging behaviour among sympatric morphs of arctic charr (Pisces: Salmonidae). Anim Behav 45:1179–1192
203	Skulason S, Snorrason SS, Noakes DLG, Ferguson MM (1996) Genetic basis of life history variations among sympatric morphs of Arctic charr, *Salvelinus alpinus.* Can J Fish Aquat Sci 53:1807–1813
204	Soto CG, Leatherland JF, Noakes DLG (1992) Gonadal histology in the self-fertilizing hermaphroditic fish *Rivulus marmoratus* (Pisces, Cyprinodontidae). Can J Zool 70:2238–2347
205	Soto CG, Noakes DLG (1994) Coloration and gender in the hermaphroditic fish *Rivulus marmoratus* Poey (Teleostei: Rivulidae). Ichthyological Explorations of Freshwaters 5:79–90

Table 1 (continued)

Publication number	Reference
206	Stewart HA, Noakes DLG, Cogliati KM, Peterson JT, Iversen MH, Schreck CB (2016) Salinity effects on plasma ion levels, cortisol, and osmolality in Chinook salmon following lethal sampling. Comp Biochem Physiol A Mol Integr Physiol 192:38–43
207	Stewart HA, Cogliati KM, Billman EJ, Chitwood R, Unrein JR, Noakes DLG, Schreck CB (2017) Effects of transportation timing on osmoregulation and survival in yearling hatchery Chinook salmon (*Oncorhynchus tshawytscha*). J Appl Aquac 29:277–290
208	Thompson NF, Leblanc CA, Romer JD, Schreck CB, Blouin MS, Noakes DLG (2016) Sex-biased survivorship and differences in migration of wild steelhead (*Oncorhynchus mykiss*) smolts from two coastal Oregon rivers. Ecol Freshw Fish 25:642–651
209	Unrein JR, Billman EJ, Cogliati KM, Chitwood R, Noakes DLG, Schreck CB (2017) Vertical self-sorting behavior in juvenile Chinook salmon (*Oncorhynchus tshawytscha*): evidence for family differences and variation in growth and morphology. Environ Biol Fishes 101:341–353
210	Vecsei P, Litvak MK, Noakes DLG, Rien T, Hochleithner M (2003) A noninvasive technique for determining sex of live adult North American sturgeons. Environ Biol Fishes 68:333–338
211	Wanzenböck J, Zaunreiter M, Wahl CM, Noakes DLG (1996) Comparison of behavioural and morphological measures of visual resolution during ontogeny of roach (*Rutilus rutilus*) and yellow perch (*Perca flavescens*). Can J Fish Aquat Sci 53:1506–1512
212	Whitmore M, Richardson S, Huff A, Goodson K, Quinn TP, Dittman AH, Johnson MA, Kamran M, Noakes DLG (2021) Homeward bound: in-river movements of adult hatchery- and natural-origin Chinook salmon in the Elk River, Oregon. N Am J Fish Manag 41:1088–1096
213	Woo PTK, Noakes DLG (eds) (2014) Salmon: biology, ecological impacts and economic importance. Fish, Fishing and Fisheries. Nova Science Publishers, New York

himself. His articles appeared in diverse outlets ranging from applied journals, such as the North American Journal of Fisheries Management, to leading academic journals, such as Current Biology (impact factor 9.6 based on 2020 data).

Research themes

David Noakes was thematically focused but conceptually broad. His research aligned with three primary themes: (1) behaviour, ecology, and evolution of fishes; (2) behaviour as it influences fish populations; and (3) native salmonine conservation. Eight focal areas are nested within the three research themes (Table 2). The first two themes encompassing six focal areas were self-identified by David in his 2010 curriculum vitae, whereas the third theme aligns with the OHRC mission and to some extent demarcates a shift in focus during the second half of his career. However, despite changes in study organisms and systems concurrent with his move to OHRC, most of his research during the latter half of his career still aligned with the two self-identified research themes, but was separated herein to recognize valuable contributions to the OHRC mission. Among the 213 articles compiled (Table 1), 172 aligned with themes and focal areas. Note that my alignment of publications with focal areas was largely subjective, and while based on publication titles and keywords, some overlap among thematic areas led to uncertainty in alignment of some publications with themes. Despite this caveat, behaviour, ecology, and evolution of fishes (research theme 1) was clearly the most active area of research comprising 75% of his efforts (Fig. 1). Native salmonine conservation was the next most accomplished theme comprising 20% of his efforts and nearly all effort during the latter portion of his career at OHRC. An overarching concept that permeated all of David's teaching and research was the notion of pattern and process. "*Pattern*" refers to natural history or the cataloguing and describing of biological diversity and the word *pattern* appeared in 124 (~ 58%) of his publications (based on PDF search via Endnote™). "*Process*" refers to the events that are responsible for the patterns of diversity at any

Table 2 Thematic and focal areas of David L.G. Noakes' research program. The first two research themes were self-identified and the third reflects the mission of the Oregon Hatchery Research Center (2014 Research Plan; available here: https://www.dfw.state.or.us/fish/ohrc/docs/2021/OHRC_Research_Plan.pdf), where he spent the later portion of his career

Research theme	Focal areas
1. Behaviour, ecology, and evolution of fishes	A. Early social behaviour of salmonid fishes B. Early life history and evolution of charrs, *Salvelinus* species C. Biology of North Atlantic eels *Anguilla anguilla* and *A. rostrata* D. Behaviour, ecology, and evolution of sticklebacks *Gasterosteus aculeatus* in Iceland
2. Behaviour as it influences fish populations	E. Impact of barrier dams on stream fishes F. Biology and conservation of sturgeon *Acipenser* species
3. Native salmonine conservation	G. Understand mechanisms that may create differences between hatchery and wild salmonines (Oregon Hatchery Research Center Mission) H. Develop approaches to manage hatchery fish that conserve and protect native salmonines

given time and appeared in 95 (~45%) publications. The phrase "*patterns and processes*" appeared in six publications. Outside of the research themes identified in Table 2, an additional 22 publications focused on applied science, that is, tools, techniques, and technologies, such as the efficacy of clove oil as a fish anesthetic, defining management and conservation units, and recently, producing wild fish phenotypes in the hatchery. Nineteen (11%) publications did not relate to his research themes; 12 of those were

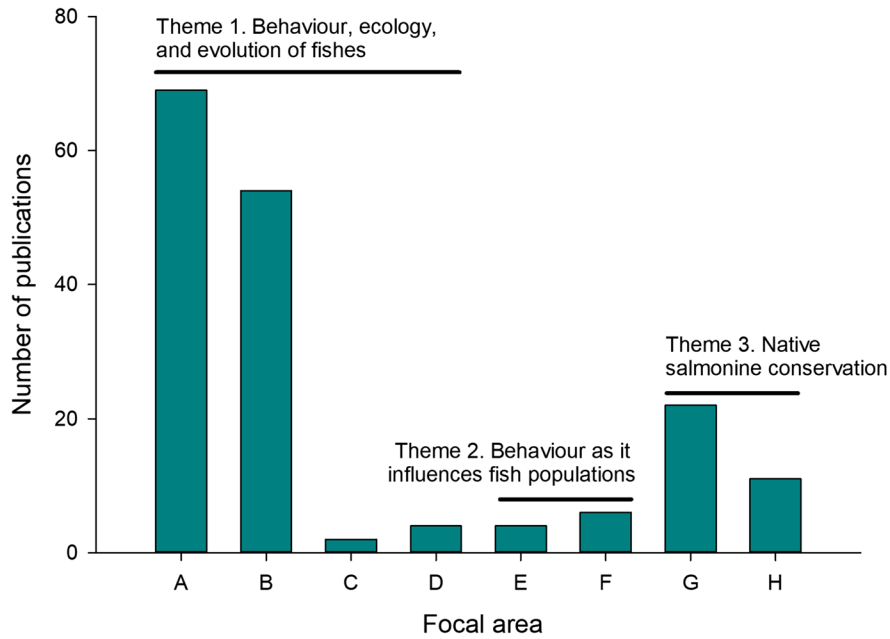

Fig. 1 Publications (1973–2021) by David L.G. Noakes organized by three main research themes and focal areas within those themes: (A) early social behaviour of salmonid fishes; (B) early life history and evolution of charrs, *Salvelinus* species; (C) biology of North Atlantic eels *Anguilla anguilla* and *A. rostrata*; (D) behaviour, ecology, and evolution of sticklebacks *Gasterosteus aculeatus* in Iceland; (E) impact of barrier dams on stream fishes; (F) biology and conservation of sturgeons *Acipenser* species; (G) mechanisms that create differences between hatchery and wild salmonines; and (H) approaches to manage hatchery fish that conserve and protect native salmonines

tributes to colleagues and five were on birds (Aves spp.; see "Taxonomy of research" below).

Taxonomy of research

Given the research themes described above, it is not surprising that a broad range of species were represented in David Noakes' research programme. One hundred-and-fifty-four publications aligned with 38 species in 16 families and three classes (Fig. 2). Salmonidae was the most prevalent taxonomic group studied, representing nearly 60% of his 154 species-specific published works ($n=92$)—the *Salvelinus* charrs comprising nearly half of that effort ($n=49$). Remarkably, the next most prevalent taxonomic group was *Homo sapiens* ($n=12$). David made concerted effort throughout his career to celebrate the field of fish biology and honour its foremothers and fathers. He led or contributed to twelve tributes, the most famous of which were Springer Developments in Environmental Biology of Fishes volumes in appreciation of Dr. Bill Ricker and an anthology in honour of Women in Ichthyology: Ethelwynn Trewavas, Rosemary Lowe-McConnell, and Eugenie Clark. He cared deeply about people, history, and tradition.

Scientific network

David Noakes was collaborative. He was remarkable at facilitating connections, particularly for his students, and fostering strong and lasting collaborations that often resulted in enduring friendships. His ability to connect people to ideas and ideas to people is evidenced by 262 unique co-authors and co-editors, including his son (Jeff) and brother (Don). Co-authors were associated with 110 unique partner institutions: 60 academic; 25 federal or national government; 13 sub-federal government; 7 industrial; 4 Indigenous organizations or communities; and 2 international commissions (data from co-author affiliations for 171 [~80%] of the publications compiled in Table 1). His co-author network spanned 17 countries. The ratio of female (45%) to male students (including committees and post-docs) mentored by David Noakes is

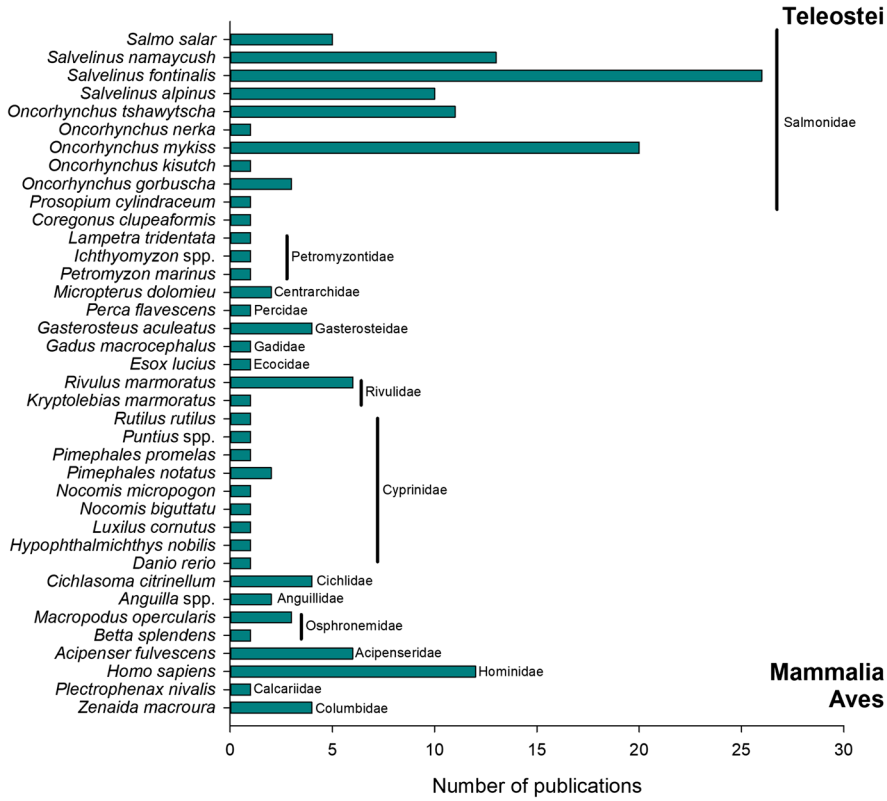

Fig. 2 Taxonomy of publications (1973–2021) by David L.G. Noakes

noteworthy and admirable, demonstrating a remarkable quality of character and strong support for diversity and inclusion in STEM, well ahead of its time.

David's co-author network (data from 158 articles downloaded from Scopus on 01 December 2021 representing ~ 75% of articles compiled in Table 1) consisted of 41 clusters, the largest containing 22 co-authors contributing to work on lampreys (Petromyzontidae) (Fig. 3). The right side of the network depicted in Fig. 3 largely represents relationships from his time at the University of Guelph (1972–2005), including strong nodes associated with Icelandic and Japanese collaborations, and primarily focuses on research theme 1 (behaviour, ecology, and evolution of fishes). The left side of the network depicts his collaborations at Oregon State University and is primarily associated with research theme 3 (native salmonine conservation). Research theme 2 (behaviour as it influences fish populations) is represented by the cluster at the top center with F.W.H Beamish at its centroid. The strongest nodes emerging from David's co-author network were Carl Schreck (Oregon State University; 18 articles), Moira Ferguson (University of Guelph; 14 articles), Skúli Skúlason (Hólar University/Icelandic Museum of Natural History; 12 articles), and Rob McLaughlin (University of Guelph; 11 articles).

Many enduring relationships were facilitated by David through scientific conferences and symposia he either co-founded or regularly attended, including the Charr Symposium, the Coregonid Symposium, Ecological and Evolutionary Ethology of Fishes, and the Yodzis Symposium. Through these meetings, he developed strong working relationships and even stronger friendships. David's co-authors only represent a fraction of his social and professional network, which included undergraduate students, university administrators and staff, resource managers, rights-holders, stakeholders, and the public—these elements of his network are difficult to quantify, but certainly helped define who he was and what he represented (Bouvier et al. this issue).

Concluding remarks

David Noakes left a strong legacy in his scientific contributions and that legacy will perpetuate via his vast lineage of students and network of colleagues, many of whom were close friends. While I attempted to synthesize his bibliography and took a cursory look at his co-author network, other contributions to this issue will certainly dive deeper into

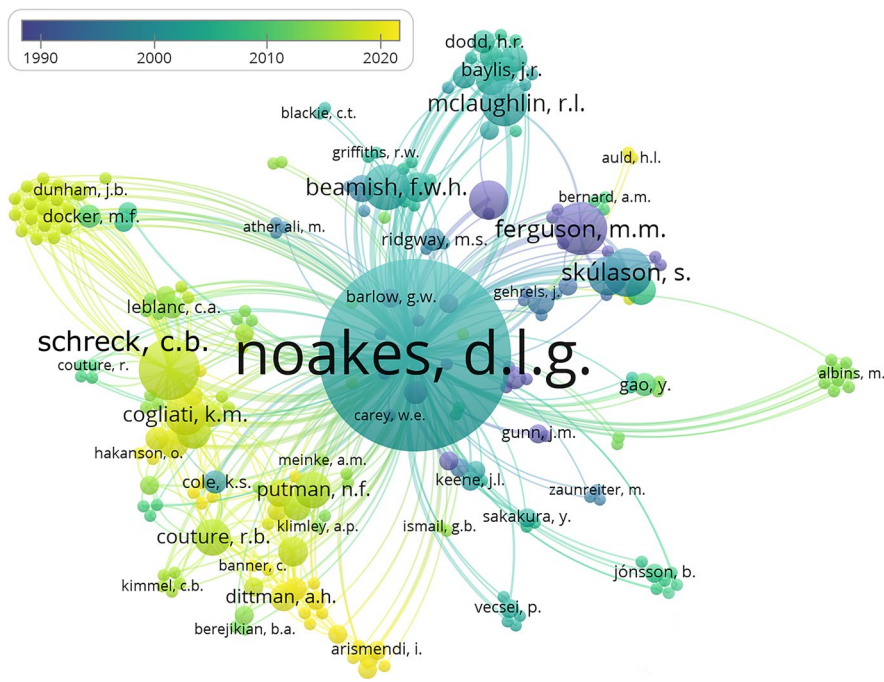

Fig. 3 Co-authorship network generated from a subset ($n = 158$) of publications by Dr. David L.G. Noakes between 1973 and 2021 (data from Scopus, 01 December 2021). Each circle represents a co-author (not all names provided) and the size of the circle represents the number of co-authorships. Colours correspond to year of publication per the scale in the top left corner of the figure. The co-author network was visualized using VOSviewer (available here: https://www.vosviewer.com/)

notable achievements, advancement of fields, and societal impacts of the career works of David L.G. Noakes. Rest easy, sir—you will be missed, but never forgotten.

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Data availability All data used in preparation of the article are freely available through electronic database searches. An Endnote™ (Clarivate, Philadelphia, PA) library was generated as part of this study and is freely available upon request.

Declarations

Ethical approval This is a synthesis of publicly available bibliometric data; no animals or human subjects were studied; therefore, no ethical approval is required.

Conflict of interest The author declares no competing interests.

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