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References:

[1] Ahn, I., Beak, S. and Lin, Z., The spreading fronts of an infective environment in a man-environment-man epidemic model, Appl. Math. Model.40 (2016) 7082-7101. · Zbl 1471.92278

[2] Alfaro, M. and Coville, J., Propagation phenomena in monostable integro-differential equations: Acceleration or not?J. Differential Equations263 (2017) 5727-5758. · Zbl 1409.35204

[3] Andreu-Vaillo, F., Mazón, J. M., Rossi, J. D. and Toledo-Melero, J. J., Nonlocal Diffusion Problems, (American Mathematical Society, Providence, RI, 2010). · Zbl 1214.45002

[4] Angenent, S. B., The zero set of a solution of a parabolic equation, J. Reine Angew. Math.390 (1988) 79-96. · Zbl 0644.35050

[5] Aronson, D. and Weinberger, H. F., Multidimensional nonlinear diffusion arising in population genetics, Adv. Math.30 (1978) 33-76. · Zbl 0407.92014

[6] Audrito, A. and Vázquez, J. L., The Fisher-KPP problem with doubly nonlinear diffusion, J. Differential Equations263(11) (2017) 7647-7708. · Zbl 1386.35197

[7] Bao, W., Du, Y., Lin, Z. and Zhu, H., Free boundary models for mosquito range movement driven by climate warming, J. Math. Biol.76 (2018) 841-875. · Zbl 1402.35283

[8] Bates, P., Fife, P., Ren, X. and Wang, X., Traveling waves in a convolution model for phase transitions, Arch. Ration. Mech. Anal.138 (1997) 105-136. · Zbl 0889.45012

[9] Bates, P. and Zhao, G., Existence, uniqueness and stability of the stationary solution to a nonlocal evolution equation arising in population dispersal, J. Math. Anal. Appl.332 (2007) 428-440. · Zbl 1114.35017

[10] Berestycki, H., Coville, J. and Vo, H., Persistence criteria for populations with non-local dispersion, J. Math. Biol.72 (2016) 1693-1745. · Zbl 1346.35202

[11] Berestycki, H. and Hamel, F., Front propagation in periodic excitable media, Comm. Pure Appl. Math.55 (2002) 949-1032. · Zbl 1024.37054

[12] Berestycki, H., Hamel, F. and Nadirashvili, N., The speed of propagation for KPP type problems. I. Periodic framework, J. Eur. Math. Soc.7 (2005) 173-213. · Zbl 1142.35464

[13] Bouin, E., Garnier, J., Henderson, C. and Patout, F., Thin front limit of an integro-differential Fisher-KPP equation with fat-tailed kernels, SIAM J. Math. Anal.50 (2018) 3365-3394. · Zbl 1403.45001

[14] Bramson, M., Maximal displacement of branching Brownian motion, Comm. Pure Appl. Math.31(5) (1978) 531-581. · Zbl 0361.60052

[15] Bunting, G., Du, Y. and Krakowski, K., Spreading speed revisited: Analysis of a free boundary model, Netw. Heterog. Media7 (2012) 583-603. · Zbl 1302.35194

[16] Cabré, X. and Roquejoffre, J.-M., The influence of fractional diffusion in Fisher-KPP equations, Comm. Math. Phys.320 (2013) 679-722. · Zbl 1307.35310

[17] Cai, J. and Gu, H., Asymptotic behavior of solutions of free boundary problems for Fisher-KPP equation, J. Dynam. Differential Equations33(2) (2021) 913-940. · Zbl 1464.34051

[18] Cai, J., Lou, B. and Zhou, M., Asymptotic behavior of solutions of a reaction diffusion equation with free boundary conditions, J. Dynam. Differential Equations26(4) (2014) 1007-1028. · Zbl 1328.35329

[19] Caffarelli, L., The regularity of free boundaries in higher dimensions, Acta Math.139(3-4) (1977) 155-184. · Zbl 0386.35046

[20] Cao, J. F., Du, Y., Li, F. and Li, W. T., The dynamics of a Fisher-KPP nonlocal diffusion model with free boundaries, J. Funct. Anal.277 (2019) 2772-2814. · Zbl 1418.35229

[21] Capasso, V. and Paveri-Fontana, S. L., A mathematical model for the 1973 cholera epidemic in the European Mediterranean region, Rev. Epidemiol. Publ.27 (1979) 121-132.

[22] Capasso, V. and Maddalena, L., Convergence to equilibrium states for a reaction-diffusion system modeling the spatial spread of a class of bacterial and viral diseases, J. Math. Biol.13 (1981/1982) 173-184. · Zbl 0468.92016

[23] Chang, C.-H. and Chen, C.-C., Travelling wave solutions of a free boundary problem for a two-species competitive model, Comm. Pure Appl. Anal.12 (2013) 1065-1074. · Zbl 1270.35166

[24] Chang, C.-H., Chen, C.-C. and Huang, C.-C., Traveling wave solutions of a free boundary problem with latent heat effect, Discrete Contin. Dyn. Syst. Ser. B26(4) (2021) 1797-1809. · Zbl 1466.35076

[25] Chang, T.-Y. and Du, Y., Long-time dynamics of an epidemic model with nonlocal diffusion and free boundaries, Electron. Res. Arch.30(1) (2022) 289-313.

[26] Chen, X., Existence, uniqueness, and asymptotic stability of traveling waves in nonlocal evolution equations, Adv. Differential Equations2 (1997) 125-160. · Zbl 1023.35513

[27] Cortázar, C., Elgueta, M. and Rossi, J. D., Nonlocal diffusion problems that approximate the heat equation with Dirichlet boundary conditions, Israel J. Math.170 (2009) 53-60. · Zbl 1178.35026

[28] Cortázar, C., Elgueta, M., Rossi, J. D. and Wolanski, N., How to approximate the heat equation with Neumann boundary conditions by nonlocal diffusion problems, Arch. Ration. Mech. Anal.187 (2008) 137-156. · Zbl 1145.35060

[29] Cortázar, C., Quirós, F. and Wolanski, N., A nonlocal diffusion problem with a sharp free boundary, Interfaces Free Bound.21 (2019) 441-462. · Zbl 1430.35240

[30] Coville, J., Dávila, J. and Martínez, S., Pulsating fronts for nonlocal dispersion and KPP nonlinearity, Ann. Inst. H. Poincaré Anal. Non Linéaire30(2) (2013) 179-223. · Zbl 1288.45007

[31] Coville, J. and Dupaigne, L., On a non-local equation arising in population dynamics, Proc. Roy. Soc. Edinb. Sect. A137 (2007) 727-755. · Zbl 1133.35056

[32] Dancer, E. N., Hilhorst, D., Mimura, M. and Peletier, L. A., Spatial segregation limit of a competition-diffusion system, European J. Appl. Math.10 (1999) 97-115. · Zbl 0982.92031

[33] de Mottoni, P., Qualitative analysis for some quasilinear parabolic systems, Inst. Math. Polish Acad. Sci. Zam.190 (1979) 11-79.

[34] del Teso, F., Endal, J. and Vazquez, J. L., The one-phase fractional Stefan problem, Math. Models Methods Appl. Sci.31 (2021) 83-131. · Zbl 1473.80010

[35] Ding, W., Du, Y. and Guo, Z. M., The Stefan problem for the Fisher-KPP equation with unbounded initial range, Cal. Var. PDEs60 (2021) 69. · Zbl 1462.35471

[36] Ding, W., Du, Y. and Liang, X., Spreading in space-time periodic media governed by a monostable equation with free boundaries, Part 1: Continuous initial functions, J. Differential Equations262 (2017) 4988-5021. · Zbl 1422.35102

[37] Ding, W., Du, Y. and Liang, X., Spreading in space-time periodic media governed by a monostable equation with free boundaries, Part 2: Spreading speed, Ann. Inst. H. Poincaré Anal. Non Linéaire36 (2019) 1539-1573. · Zbl 1421.35191

[38] Y. Du, J. Fang and N. Sun, A delay induced nonlocal problem with free boundary, preprint (2021).

[39] Du, Y., Gui, C., Wang, K. and Zhou, M., Semi-waves with \(\operatorname{\Lambda} \)-shaped free boundary for nonlinear Stefan problems: Existence, Proc. Amer. Math. Soc.149 (2021) 2091-2104. · Zbl 1461.35249

[40] Du, Y. and Guo, Z. M., The Stefan problem for the Fisher-KPP equation, J. Differential Equations253 (2012) 996-1035. · Zbl 1257.35110

[41] Du, Y., Guo, Z. M. and Peng, R., A diffusive logistic model with a free boundary in time-periodic environment, J. Funct. Anal.265 (2013) 2089-2142. · Zbl 1282.35419

[42] Y. Du, Y. Hu and X. Liang, A climate shift model with free boundary: Enhanced invasion, J. Dynam. Differential. Equations, https://doi.org/10.1007/s10884-021-10031-3.

[43] Du, Y., Li, F. and Zhou, M., Semi-wave and spreading speed of the nonlocal Fisher-KPP equation with free boundaries, J. Math. Pure Appl.154 (2021) 30-66. · Zbl 1473.35665

[44] Y. Du, W.-T. Li, W. Ni and M. Zhao, Finite or infinite spreading speed of an epidemic model with free boundary and double nonlocal effects, preprint, 2020.

[45] Du, Y. and Liang, X., Pulsating semi-waves in periodic media and spreading speed determined by a free boundary model, Ann. Inst. H. Poincaré Anal. Non Linéaire32 (2015) 279-305. · Zbl 1321.35263

[46] Du, Y. and Lin, Z., Spreading-Vanishing dichotomy in the diffusive logistic model with a free boundary, SIAM J. Math. Anal.42 (2010) 377-405. · Zbl 1219.35373

[47] Du, Y. and Lin, Z., The diffusive competition model with a free boundary: Invasion of a superior or inferior competitor, Discrete Cont. Dyn. Syst. B.19 (2014) 3105-3132. · Zbl 1310.35245

[48] Du, Y. and Lou, B., Spreading and vanishing in nonlinear diffusion problems with free boundaries, J. Eur. Math. Soc.17 (2015) 2673-2724. · Zbl 1331.35399

[49] Du, Y., Lou, B. and Zhou, M., Nonlinear diffusion problems with free boundaries: Convergence, transition speed and zero number arguments, SIAM J. Math. Anal.47 (2015) 3555-3584. · Zbl 1321.35086

[50] Du, Y., Lou, B. and Zhou, M., Spreading and vanishing for nonlinear Stefan problems in high space dimensions, J. Elliptic Parabolic Equations2 (2016) 297-321. · Zbl 1386.35022

[51] Du, Y. and Matano, H., Convergence and sharp thresholds for propagation in nonlinear diffusion problems, J. Eur. Math. Soc.12 (2010) 279-312. · Zbl 1207.35061

[52] Du, Y., Matano, H. and Wang, K., Regularity and asymptotic behavior of nonlinear Stefan problems, Arch. Ration. Mech. Anal.212 (2014) 957-1010. · Zbl 1293.35331

[53] Du, Y., Matsuzawa, H. and Zhou, M., Sharp estimate of the spreading speed determined by nonlinear free boundary problems, SIAM J. Math. Anal.46 (2014) 375-396. · Zbl 1296.35219

[54] Du, Y., Matsuzawa, H. and Zhou, M., Spreading speed and profile for nonlinear Stefan problems in high space dimensions, J. Math. Pures Appl.103 (2015) 741-787. · Zbl 1310.35060

[55] Du, Y. and Ni, W., Analysis of a West Nile virus model with nonlocal diffusion and free boundaries, Nonlinearity33 (2020) 4407-4448. · Zbl 1439.35220

[56] Y. Du and W. Ni, Approximation of random diffusion equation by nonlocal diffusion equation in free boundary problems of one space dimension, to appear in Comm. Contemp. Math., arXiv:2003.05560.

[57] Y. Du and W. Ni, Semi-wave, traveling wave and spreading speed for monostable cooperative systems with nonlocal diffusion and free boundaries, preprint (2020), arXiv:2010.01244. · Zbl 1479.35191

[58] Y. Du and W. Ni, The high dimensional Fisher-KPP nonlocal diffusion equation with free boundary and radial symmetry, preprint (2021), arXiv:2102.05286.

[59] Du, Y., Quirós, F. and Zhou, M., Logarithmic corrections in Fisher-KPP type porous medium equations, J. Math. Pure Appl.136 (2020) 415-455. · Zbl 1439.35238

[60] Du, Y., Wang, M. and Zhao, M., Two species nonlocal diffusion systems with free boundaries, Discrete Contin. Dyn. Syst.-Ser. A42 (2022) 1127-1162. · Zbl 1483.35347

[61] Du, Y., Wang, M. and Zhou, M., Semi-wave and spreading speed for the diffusive competition model with a free boundary, J. Math. Pure Appl.107 (2017) 253-287. · Zbl 1377.35136

[62] Du, Y., Wei, L. and Zhou, L., Spreading in a shifting environment modeled by the diffusive logistic equation with a free boundary, J. Dynam. Differential Equations30 (2018) 1389-1426. · Zbl 1408.35227

[63] Du, Y. and Wu, C.-H., Spreading with two speeds and mass segregation in a diffusive competition system with free boundaries, Cal. Var. PDEs57 (2018) 52. · Zbl 1396.35028

[64] Y. Du and C.-H. Wu, Classification of the spreading behaviors of a two-species diffusion-competition system with free boundaries, Cal. Var. PDEs to appear. · Zbl 1485.35432

[65] El-Hachem, M., McCue, S. W. and Simpson, M. J., A sharp-front moving boundary for malignant invasion, Physica D412 (2020) 132639, https://doi.org/ 10.1016/j.physd.2020.132639.

[66] El-Hachem, M., McCue, S. W. and Simpson, M. J., Invading and receding sharp-fronted traveling waves, Bull. Math. Biol.83 (2021) 35, https://doi.org/10.1007. · Zbl 1460.92232

[67] Fadai, N. T., Semi-infinite traveling waves arising in a general reaction-diffusion Stefan model, Nonlinearity34 (2021) 725-743. · Zbl 1458.35107

[68] Fadai, N. T. and Simpson, M. J., New traveling wave solutions of the Porous-Fisher model with a moving boundary, J. Phys. A: Math. Theor.53 (2020) 095601.

[69] Fang, J. and Faye, G., Monotone traveling waves for delayed neural field equations, Math. Models Methods Appl. Sci.26 (2016) 1919-1954. · Zbl 06630597

[70] Fila, M. and Souplet, P., Existence of global solutions with slow decay and unbounded free boundary for a superlinear Stefan problem, Interfaces Free Bound.3 (2001) 337-344. · Zbl 1006.35103

[71] Finkelshtein, D. and Tkachov, P., Accelerated nonlocal nonsymmetric dispersion for monostable equations on the real line, Appl. Anal.98 (2019) 756-780. · Zbl 1407.35027

[72] Fisher, R., The wave of advance of advantage genes, Ann. Eugenics7 (1937) 335-369.

[73] Friedman, A., The Stefan problem in several space variables, Trans. Amer. Math. Soc.132 (1968) 51-87. · Zbl 0162.41903

[74] Garnier, J., Accelerating solutions in integro-differential equations, SIAM J. Math. Anal.43 (2011) 1955-1974. · Zbl 1232.47058

[75] Gärtner, J., Location of wave fronts for the multidimensional KPP equation and Brownian first exit densities, Math. Nachr.105 (1982) 317-351.

[76] Gärtner, J. and Freidlin, M. I., On the propagation of concentration waves in periodic and random media, Sov. Math. Dokl.20 (1979) 1282-1286. · Zbl 0447.60060

[77] Ghidouche, H., Souplet, P. and Tarzia, D., Decay of global solutions, stability and blow-up for a reaction-diffusion problem with free boundary, Proc. Amer. Math. Soc.129 (2001) 781-792. · Zbl 0959.35087

[78] Gilding, B. H. and Kersner, R., Traveling Waves in Nonlinear Diffusion-Convection Reaction, , Vol. 60 (Birkhäuser Verlag, Basel, 2004). · Zbl 1073.35002

[79] Girardin, L. and Lam, K. Y., Invasion of open space by two competitors: Spreading properties of monostable two-species competition-diffusion systems, Proc. London Math. Soc.119 (2019) 1279-1335. · Zbl 1428.35158

[80] Girardin, L. and Nadin, G., Traveling waves for diffusive and strongly competitive systems: Relative motility and invasion speed, Eur. J. Appl. Math.26 (2015) 521-534. · Zbl 1375.92049

[81] Gu, H., Lou, B. and Zhou, M., Long time behavior of solutions of Fisher-KPP equation with advection and free boundaries, J. Funct. Anal.269(6) (2015) 1714-1768. · Zbl 1335.35102

[82] Guo, J. and Wu, C. H., On a free boundary problem for a two-species weak competition system, J. Dynam. Differential Equations24 (2012) 873-895. · Zbl 1263.35132

[83] Guo, J.-S. and Wu, C.-H., Dynamics for a two-species competition-diffusion model with two free boundaries, Nonlinearity28 (2015) 1-27. · Zbl 1316.92066

[84] Gurney, W. S. C. and Nisbet, R. M., The regulation of inhomogeneous populations, J. Theoret. Biol.52 (1975) 441-457.

[85] Gurtin, M. E. and MacCamy, R. C., On the diffusion of biological populations, Math. Biosci.33 (1977) 35-49. · Zbl 0362.92007

[86] Hamel, F. and Roques, L., Fast propagation for KPP equations with slowly decaying initial conditions, J. Differential Equations249 (2010) 1726-1745. · Zbl 1213.35100

[87] Hilhorst, D., Mimura, M. and Schätzle, R., Vanishing latent heat limit in a Stefan-like problem arising in biology, Nonlinear Anal. Real World Appl.4 (2003) 261-285. · Zbl 1049.92035

[88] Hu, Y., Hao, X. and Du, Y., Spreading under shifting climate by a free boundary model: Invasion of deteriorated environment, Comm. Contemp. Math.23 (2021) 2050077. · Zbl 1479.35963

[89] Hu, Y., Hao, X., Song, X. and Du, Y., A free boundary problem for spreading under shifting climate, J. Differential Equations269 (2020) 5931-5958. · Zbl 1448.35584

[90] Kanel', Ja. I., Stabilization of the solutions of the equations of combustion theory with finite initial functions, Mat. Sb.65 (1964) 398-413.

[91] Kaneko, Y. and Matsuzawa, H., Spreading speed and sharp asymptotic profiles of solutions in free boundary problems for nonlinear advection-diffusion equations, J. Math. Anal. Appl.428 (2015) 43-76. · Zbl 1325.35292

[92] Kaneko, Y., Matsuzawa, H. and Yamada, Y., Asymptotic profiles of solutions and propagating terrace for a free boundary problem of nonlinear diffusion equation with positive bistable nonlinearity, SIAM J. Math. Anal.52 (2020) 65-103. · Zbl 1452.35261

[93] Kan-on, Y., Fisher wave fronts for the Lotka-Volterra competition model with diffusion, Nonlinear Anal. TMA28(1) (1997) 145-164. · Zbl 0868.35053

[94] Kawai, Y. and Yamada, Y., Multiple spreading phenomena for a free boundary problem of a reaction-diffusion equation with a certain class of bistable nonlinearity, J. Differential Equations261(1) (2016) 538-572. · Zbl 1430.35277

[95] Khan, K., Liu, S., Schaerf, T. M. and Du, Y., Invasive behavior under competition via a free boundary model: A numerical approach, J. Math. Biol.83 (2021) 23. · Zbl 1477.35285

[96] K. Khan, T. M. Schaerf and Y. Du, Effects of environmental heterogeneity on species spreading via numerical analysis of some free boundary models, to appear in Discrete Contin. Dyn. Syst. Ser. B.

[97] Kinderlehrer, D. and Nirenberg, L., The smoothness of the free boundary in the one phase Stefan problem, Comm. Pure Appl. Math.31 (1978) 257-282. · Zbl 0391.35060

[98] Kolmogorov, A. N., Petrovski, I. G. and Piskunov, N. S., A study of the diffusion equation with increase in the amount of substance, and its application to a biological problem, Bull. Moscow Univ. Math. Mech.1 (1937) 1-25.

[99] Lewis, M. A., Renclawowicz, J. and van den Driessche, P., Traveling waves and spread rates for a West Nile virus model, Bull. Math. Biol.68 (2006) 3-23. · Zbl 1334.92414

[100] Lei, C., Nie, H., Dong, W. and Du, Y., Spreading of two competing species governed by a free boundary model in a shifting environment, J. Math. Anal. Appl.462 (2018) 1254-1282. · Zbl 1390.35377

[101] Li, F., Liang, X. and Shen, W., Diffusive KPP equations with free boundaries in time almost periodic environments: I. Spreading and vanishing dichotomy, Discrete Contin. Dyn. Syst. Ser. A36 (2016) 3317-3338. · Zbl 1334.35123

[102] Li, F., Liang, X. and Shen, W., Diffusive KPP equations with free boundaries in time almost periodic environments: II. Spreading speeds and semi-wave, J. Differential Equations261 (2016) 2403-2445. · Zbl 1337.35065

[103] Li, L., Sheng, W. J. and Wang, M. X., Systems with nonlocal versus local diffusions and free boundaries, J. Math. Anal. Appl.483 (2020) 123646. · Zbl 1429.35213

[104] Liang, X., Semi-wave solutions of KPP-Fisher equations with free boundaries in spatially almost periodic media, J. Math. Pures Appl.127 (2019) 299-308. · Zbl 1420.35129

[105] Liang, X. and Zhao, X.-Q., Asymptotic speeds of spread and traveling waves for monotone semiflows with applications, Comm. Pure Appl. Math.60 (2007) 1-40. · Zbl 1106.76008

[106] Liang, X. and Zhou, T., Transition semi-wave solutions of reaction diffusion equations with free boundaries, J. Differential Equations267(10) (2019) 5601-5630. · Zbl 1421.35048

[107] Lin, Z., A free boundary problem for a predator-prey model, Nonlinearity20 (2007) 1883-1892. · Zbl 1126.35111

[108] Lin, Z. and Zhu, H., Spatial spreading model and dynamics of West Nile virus in birds and mosquitoes with free boundary, J. Math. Biol.75(6-7) (2017) 1381-1409. · Zbl 1373.35321

[109] Liu, S., Du, Y. and Liu, X., Numerical studies of a class of reaction-diffusion equations with Stefan conditions, Int. J. Comp. Math.97 (2020) 959-979. · Zbl 1480.65214

[110] Liu, S. and Liu, X., Krylov implicit integration factor method for a class of stiff reaction-diffusion systems with moving free boundaries, Discrete Cont. Dynam. Syst. B25 (2020) 141-159. · Zbl 1427.65172

[111] Liu, Y., Guo, Z., El Smaily, M. and Wang, L., A Wolbachia infection model with free boundary, J. Biol. Dyn.14(1) (2020) 515-542. · Zbl 1447.92447

[112] Liu, S., Huang, H. and Wang, M. X., Asymptotic spreading of a diffusive competition model with different free boundaries, J. Differential Equations266(8) (2019) 4769-4799. · Zbl 1412.35166

[113] Mimura, M., Yamada, Y. and Yotsutani, S., A free boundary problem in ecology, Japan J. Appl. Math.2 (1985) 151-186. · Zbl 0593.92019

[114] Matano, H., Asymptotic behavior of the free boundaries arising in one phase Stefan problems in multi-dimensional spaces, Nonlinear Partial Differential Equations in Applied Science, eds. Fujita, H., Lax, P. D. and Strang, G., , Vol. 81 (North-Holland, Amsterdam, 1983), pp. 133-151.

[115] Natan, R., Klein, E., Robledo-Arnuncio, J. J. and Revilla, E., Dispersal kernels: Review, in Dispersal Ecology and Evolution, eds. Clobert, J., Baguette, M., Benton, T. G. and Bullock, J. M. (Oxford University Press, Oxford, UK, 2012), pp. 187-210.

[116] Piqueras, M.-A., Company, R. and Jodar, L., A front-fixing numerical method for a free boundary nonlinear diffusion logistic population model, J. Comput. Appl. Math.309 (2017) 473-481. · Zbl 1349.92129

[117] Rawal, N., Shen, W. and Zhang, A., Spreading speeds and traveling waves of nonlocal monostable equations in time and space periodic habitats, Discrete Contin. Dyn. Syst.35 (2015) 1609-1640. · Zbl 1302.45003

[118] Roquejoffre, J.-M., Rossi, L. and Roussier-Michon, V., Sharp large time behavior in N-dimensional Fisher-KPP equations, Discrete Contin. Dyn. Syst.39(12) (2019) 7265-7290. · Zbl 1425.35102

[119] Shen, W. and Xie, X., Approximations of random dispersal operators/equations by nonlocal dispersal operators/equations, J. Differential Equations259(12) (2015) 7375-7405. · Zbl 1328.35069

[120] Skellam, J. G., Random dispersal in theoretical populations, Biometrika38 (1951) 196-218. · Zbl 0043.14401

[121] Souganidis, P. E. and Tarfulea, A., Front propagation for integro-differential KPP reaction-diffusion equations in periodic media, NoDEA Nonlinear Differential Equations Appl.26(4) (2019) 29. · Zbl 1423.35212

[122] Sun, Y.-J., Li, W.-T. and Wang, Z.-C., Traveling waves for a nonlocal anisotropic dispersal equation with monostable nonlinearity, Nonlinear Anal.74 (2011) 814-826. · Zbl 1211.35068

[123] Sun, N. and Fang, J., Propagation dynamics of Fisher-KPP equation with time delay and free boundaries, Calc. Var. Partial Differential Equations58 (2019) 148. · Zbl 1418.35239

[124] Sun, N., Lou, B. and Zhou, M., Fisher-KPP equation with free boundaries and time-periodic advections, Calc. Var. PDEs56 (2017) 61. · Zbl 1386.35151

[125] Tian, C. and Ruan, S., On an advection-reaction-diffusion competition system with double free boundaries modeling invasion and competition of Aedes albopictus and Aedes aegypti mosquitoes, J. Differential Equations265 (2018) 4016-4051. · Zbl 1403.35308

[126] Wang, J. B. and Zhao, X.-Q., Uniqueness and global stability of forced waves in a shifting environment, Proc. Amer. Math. Soc.147(4) (2019) 1467-1481. · Zbl 1407.35116

[127] Wang, J. and Wang, M., Free boundary problems with nonlocal and local diffusions I: Global solution, J. Math. Anal. Appl.490(2) (2020) 123974. · Zbl 1439.35581

[128] Wang, M. X., On some free boundary problems of the Lotka-Volterra type prey-predator model, J. Differential Equations256 (2014) 3365-3394. · Zbl 1317.35110

[129] Wang, M. X., A diffusive logistic equation with a free boundary and sign-changing coefficient in time-periodic environment, J. Funct. Anal.270 (2016) 483-508. · Zbl 1335.35128

[130] Wang, M. X. and Zhang, Y., Note on a two-species competition-diffusion model with two free boundaries, Nonlinear Anal.159 (2017) 458-467. · Zbl 1371.35367

[131] Wang, M. X. and Zhao, J. F., A free boundary problem for a predator-prey model with double free boundaries, J. Dynam. Differential Equations29 (2017) 957-979. · Zbl 1373.35164

[132] Wang, R. and Du, Y., Long-time dynamics of a diffusive epidemic model with free boundaries, Discrete Contin. Dyn. Syst.-Ser. B26 (2021) 2201-2238. · Zbl 1466.35047

[133] Wang, Z., Nie, H. and Du, Y., Spreading speed for a West Nile virus model with free boundary, J. Math. Biol.79 (2019) 433-466. · Zbl 1421.35391

[134] Wei, L., Zhang, G. and Zhou, M., Long time behavior for solutions of the diffusive logistic equation with advection and free boundary, Calc. Var. Partial Differential Equations55(4) (2016) 95. · Zbl 1377.35290

[135] Weinberger, H. F., Long-time behavior of a class of biological models, SIAM J. Math. Anal.13 (1982) 353-396. · Zbl 0529.92010

[136] Weinberger, H. F., On spreading speeds and traveling waves for growth and migration in periodic habitat, J. Math. Biol.45 (2002) 511-548. · Zbl 1058.92036

[137] WHO, Cholera vaccines: WHO position paper, Weekly Epidemiological Record85(13) (2010) 117-128, https://pubmed.ncbi.nlm.nih.gov/20349546.

[138] Xu, W. B., Li, W.-T. and Lin, G., Nonlocal dispersal cooperative systems: Acceleration propagation among species, J. Differential Equations268(3) (2020) 1081-1105. · Zbl 1428.35074

[139] Yagisita, H., Existence and nonexistence of traveling waves for a nonlocal monostable equation, Publ. Res. Inst. Math. Sci.45(4) (2009) 925-953. · Zbl 1191.35093

[140] Yang, J. and Lou, B., Traveling wave solutions of competitive models with free boundaries, Discrete Contin. Dyn. Syst. Ser. B19 (2014) 817-826. · Zbl 1292.35075

[141] Zhang, W., Liu, Z. and Zhou, L., A free boundary problem of a predator-prey model with a nonlocal reaction term, Z. Angew. Math. Phys.72 (2021) 77. · Zbl 1464.35407

[142] Zhao, M., Li, W.-T. and Du, Y., The effect of nonlocal reaction in an epidemic model with nonlocal diffusion and free

boundaries, Comm. Pure Appl. Anal.19 (2020) 4599-4620. · Zbl 1460.35400

[143] Zhao, M., Li, W.-T. and Ni, W., Spreading speed of a degenerate and cooperative epidemic model with free boundaries, Discrete Contin. Dyn. Syst. Ser. B25 (2020) 981-999. · Zbl 1428.35175

[144] Zhao, M., Zhang, Y., Li, W.-T. and Du, Y., The dynamics of a degenerate epidemic model with nonlocal diffusion and free boundaries, J. Differential Equations269 (2020) 3347-3386. · Zbl 1442.35486

[145] Zhou, P. and Lin, Z. G., Global existence and blowup of a nonlocal problem in space with free boundary, J. Funct. Anal.262 (2012) 3409-3429. · Zbl 1234.35325

[146] Zlatŏs, A., Sharp transition between extinction and propagation of reaction, J. Amer. Math. Soc.19 (2006) 251-263. · Zbl 1081.35011